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ABSTRACT

Two classroom studies, one conducted in the spring of 1985 and the second in the spring of 1986, showed that many high school students do not differentiate between heat and temperature; instead, they have a single concept that contains some of the features of heat and some of the features of temperature. Because the distinction between these two phenomena is essential to an understanding of other thermal phenomena in both physical and biological systems, researchers developed Microcomputer-Based Laboratories (MBL) to facilitate students' differentiation of heat and temperature. Lessons focusing on the quantitative relationships between the amount of heat, mass and temperature change, heat storage capacity, cooling curves, and latent heat were developed in two formats, computer-based and traditional. In the computer-based lessons, students use the computer as a laboratory tool to record heat and temperature data and to display them as graphs and tables. Results indicate that the MBL can help students understand more clearly the quantification of heat and distinguish between heat and temperature. The MBL allows students to collect data more quickly and with greater precision, and it frees them from performing calculations and drawing graphs. Students need plenty of time to experiment with and discuss thermal phenomena. Lesson plans are included for the topics of: (1) heat and temperature; (2) heat storage capacity; and (3) latent heat. Eighteen tables analyze the results of interviews and tests. Tests and interviews from both the 1985 and 1986 studies are presented in 17 appendices. (CW)

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THE DIFFERENTIATION OF HEAT AND TEMPERATURE: AN EVALUATION OF THE EFFECT OF MICROCOMPUTER TEACHING ON STUDENTS' MISCONCEPTIONS

Technical Report
December 1986

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The Differentiation of Heat and Temperature: An Evaluation of the Effect of Microcomputer Teaching on Students' Misconceptions

Technical Report
December 1986

prepared by Marianne Wiser

Heat and Temperature

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INTRODUCTION

Our target of difficulty is basic thermal physics, especially the differentiation of heat and temperature. Microcomputers can be used in at least three different ways to teach about heat and temperature. They can be used as laboratory tools to collect and summarize real data (Microcomputer Based Laboratories or MBL). Software can also be written to simulate laboratory experiments on the screen (Laboratory Simulations). This differs from MBL in that the data "collected" are ideal data; there is no link between the computer and the physical world whereas, with MBL, students are using laboratory instruments such as a thermal probe interfaced with the computer. Finally, software can be written to present molecular models to the students, demonstrating the molecular behavior underlying thermal phenomena.

We view learning as the interaction between the information presented in class and in textbooks about a domain of knowledge and the internal mental state of the student (i.e. the pre-existing knowledge a student has about that domain) (Driver and Erikson, 1983). Consequently we have three interrelated goals: to characterize the initial state (i.e. the ideas and concepts that the students have developed on their own and bring to the classroom), to develop a microcomputer based curriculum that is optimally adapted to those pre-conceptions, and to monitor the resulting interaction between the students and the curriculum. This is obviously a feedback process: by watching students in the classroom and evaluating the effects of our teaching interventions, we update our characterization of the students' conceptions and modify the curriculum accordingly. A fourth goal is to develop suitable assessment methods the teaching interventions effects.

Our group has conducted so far three major studies. The first and third studies evaluate the effect of different computer teaching interventions in the classroom. They were conducted in the Spring of 1985 and the Spring of 1986 respectively. In both studies we used two assessment methods: a set of quantitative problems, similar to those found in traditional science tests, and a series of conceptual, qualitative questions with a broader scope, which probed the students' conceptualization of thermal phenomena. This conceptual evaluation took the form of an individual clinical interview in the first study and of a written, multiple-choice test in the third study. The second study, conducted in the Fall of 1985, assesses the reliability of the written, multiple-choice test as a tool for characterizing students' conceptual systems.

The results of the three studies are reported as follows:

First Classroom Study (Spring of 1985)
    Rationale and procedure: 1985 Technical Report (Wiser, 1985)
    Results of the Quantitative Problems Test: 1985 Technical Report
    Further analysis of the Quantitative Problems Test: present Technical Report
    Results of the Clinical Interviews: present Technical Report

Development of a written version of the verbal interview (Fall of 1985): present Technical Report

Second Classroom Study (Spring 1986)
    Rationale and procedure: present Technical Report
    Results of the Quantitative Problems Test: present Technical Report
    Brief analysis of the Conceptual Test: present Technical Report
    Detailed analysis of the Conceptual Test: Technical Report 1987 (forthcoming)

CONCEPTUAL FRAMEWORK

Heat and temperature are part of most science courses taught at the elementary and secondary level. The physics of heat is the first contact that the student has with energy transfer, a set of phenomena which is central to courses in physics, chemistry, and biology. Given the importance of heat and temperature to the study of all natural sciences, it is essential that the students' encounters with these concepts be successful. However, high school and college teachers find that thermal concepts are extremely difficult for their students to master. Calorie, freezing point, latent heat and specific heat are just a few of the thermal concepts that students generally fail to understand satisfactorily. Teachers attribute the students' difficulties at least in part to their failure to differentiate between heat and temperature. Lack of differentiation would indeed account for the students' poor learning since most thermal variables, laws and principles are based on the distinction and relation between heat and temperature. Therefore we have selected the differentiation of heat and temperature as our target of difficulty.

The development of the concepts of heat and temperature has been studied from two different points of view: the development of general cognitive abilities and domain specific knowledge. Strauss has investigated 3-to-13 year old children's concept of temperature and has related it to the development of mathematical reasoning (Strauss, Stavy and Orpaz,1976). Shayer and Wylam (1981) have related the development of the concepts of heat and temperature to Piagetian stages, claiming that the differentiation is not achieved until the formal operational stage. Our approach is different: it focuses on the content of thermal knowledge, rather than on logico-mathematical abilities. Research carried out by Erikson (1979,1980), Driver and Easley (1978), Tiberghien (Tiberghien and Barboux, 1983), McDermott (Rosenquist, Popp and McDermott,1982a, 1982b) and Wiser (1985; in press) has revealed that students' conceptualization of thermal phenomena is quite different from the textbook account of the same phenomena and, like their misconceptions in mechanics, quite robust.

Not only is the central concept--*heat* -- undifferentiated with respect to the physicist's heat and temperature but it is embedded in a very different network of concepts and relations in which it plays a different explanatory role. We believe that this alternative framework is resistant to change not only because it has strong intuitive appeal but because the theory to be learned is not compatible with it. Consequently the information presented in class tends to be either distorted so that it can fit into the students' framework or ignored because it does not make sense within this framework; in both cases, the students' initial system of beliefs is affected very little. We believe that in order to make the textbook theory accessible to the students, and in particular to induce the differentiation between heat and temperature, the content and manner of teaching must take the students' own framework into account. The lesson topics should be ones that will show students that their interpretation is not appropriate, because it leads to wrong or conflicting predictions. At the same time the material should be presented in such a way as to make the textbook concepts and principles easy to abstract and mentally represent. In other words, we view learning about thermal physics as a major conceptual reorganization and believe that microcomputers can be useful in several ways, detailed in the next sections.

Our goal has thus been twofold: (1) to characterize the students' conceptualization of thermal phenomena and (2) to design microcomputer based teaching interventions aimed at dispelling the major misconceptions held by the students and at replacing the students' initial conceptualization by the textbook theory. The two enterprises "build" on each other, of course. As we observe the students' reactions in the classroom and analyze the pre-/post-tests, our understanding of the students' conceptual system before, during and after the teaching intervention becomes clearer and clearer. And as we understand the misconceptions and the components of the learning process more clearly, we can devise more effective teaching interventions.

The characterization of the students' conceptualizations presented below will help make clear why Microcomputer Based Laboratories (MBL) are considered particularly well suited for the task. To anticipate, MBL tools provide students with both hands-on experience and sophisticated data collecting and analysis. They give students flexibility and allow them to carry on many more lab experiments in a fixed amount of time than traditional laboratory methods. MBL can be extended with Laboratory Simulations which allow students to experiment with situations difficult or impossible to implement in "real-life" laboratories. More importantly they give students more direct phenomenological access to important concepts such as *unit of heat.* However the results of our studies reveal that, although they give students an advantage at solving quantitative problems involving the relation between heat and temperature, MBL by itself is not enough to drive the conceptual differentiation between heat and temperature (Wiser,1985). Our results suggest that the differentiation between heat and temperature could be easier to achieve with the help of a kinetic molecular model. We are in the process of developing such a computer-generated model. It can be used by itself or be combined with MBL to demonstrate the mechanisms underlying heating, temperature change and phase change at the molecular level at the same time as the student is taking macroscopic measurements of heat and temperature.

Our classroom experience also points to the need to alert teachers to their students' misconceptions as explicitly and in as much detail as possible. We will consider those different points in turn. We will first present the alternative framework held by most students; we will then review the results of the three major studies we have carried out so far and discuss how those results are influencing our present research.

STUDENTS' CONCEPTUALIZATION OF THERMAL PHENOMENA

The following characterization of students' ideas about thermal phenomena is based on a large number of clinical interviews involving mostly ninth-graders, and a few college students without a physics background (Wiser, 1985; in press).

Students think of heat basically as an intensive quality which is measured with a thermometer: the stronger the heat, the higher the level in the thermometer. Many think of heat as having force and actually pushing the thermometer up. Cold is an entity separate and opposite of heat. Like heat, it has force and is measured with a thermometer. Thus, temperature (the thermometer reading) is seen either as the synonym of heat, or as a superordinate term for both heat and cold, or as the measure of heat and cold. Students conceive of thermal phenomena as produced by sources of heat (or cold) acting on passsive recipients ("passive" in the sense that the state of the recipient has no influence on the heat transfer). Hot sources emit heat spontaneously: they apply more or less intense heat depending on their temperature. (For example, the heat emitted by a stove burner on a high setting is hotter than the heat emitted by a burner on a low setting.) The students have no concept of *amount of heat* in the extensive sense. They rarely use the words, and when they do it is in the sense of heat intensity. They account for extensivity through a causal schema: larger sources have more effect not because they give off more heat but because they have more contact area with the recipient, thereby applying their heat to a larger portion of the recipient. A source will also have more effect the longer it stays in contact with the recipient. For example, a large amount of boiling water has the same heat as a small amount but will melt more snow because it covers more of the snow and/or because it stays hot longer.

Because students think of sources of heat as communicating *their heat* (i.e. heat of a certain degree or intensity) to recipients, the physicist's notion of fixed points is impossible to understand. How could the recipient stay at the same temperature while it is changing state since it is receiving heat and therefore must be increasing in hotness? Students interpret fixed points in a way consistent with their own framework: the fact that temperature stays constant during phase change is either ignored or is interpreted as an absolute limit for the substance. For example, the freezing point of a substance is "as cold as it can get" (even in its solid state) or "no matter how much cold is applied to the substance, its temperature will not get lower." Thermal equilibrium, in the physicists' sense, is also not intelligible because it requires a concept of heat distinct from temperature. However, students sometimes can understand that two bodies in contact reach the same temperature. They can do so on the basis of a single thermal concept: The source cannot make the recipient hotter than itself because it is communicating to the recipient heat of a certain degree. Specific heat phenomena are also hard to understand. If the same heat is applied to the same amount of two different substances, the temperature changes should be the same.

The students' concept of heat is clearly undifferentiated with respect to the physicist's heat and temperature. It is both intensive--its measure is the same at every point in the source-- and extensive-- the heat in a larger quantity of hot water has more effect. Like the physicist's heat, the student's heat is transmitted from hot to cold objects and can be generated by chemical reactions. Like temperature, it is measured with a thermometer, its intensity corresponds to felt hotness and (at least for some students) it reaches the same level in two objects in contact. It lacks critical components of both heat and temperature: the notion of amount of heat, for example, or a clear understanding of thermal equilibrium.

It is not surprising that this undifferentiated concept should be resistant to change: the students' concept of heat is well articulated, rich and coherent. It is adapted to everyday experience of thermal phenomena. It captures the fact that hot and cold are different sensations, for example, and that it takes longer to boil more water (because the heat has to spread through more water). Everyday experiences may even reinforce misconceptions. For example, the dials on stoves and ovens are marked in degrees; since stoves and ovens are sources of heat, one is led to believe that, for example, 350°F is the measure of the heat given off by the flame. More importantly, heat plays a very different explanatory role in the students' account of thermal phenomena than heat and temperature do in the physicist's account of the same phenomena. For example, in physics, thermal equillibrium states the conditions under which heat is exchanged. In the students' conceptualization there is no need to account for heat exchanges: sources emit heat spontaneously. If it is part of the students' beliefs at all, thermal equilibrium is seen as a consequence of the fact that sources transmit heat of a certain temperature to the recipients. And causal schemata are at the center of students' explanations whereas they are not part of modern physics (see also, de Kleer and Brown,1985). In other words, the students' undifferentiated concept is embedded in a very different theory from the scientifically accepted one. If they are to learn thermal physics, the students must undergo a deep conceptual reorganization--a theory change (Posner, Strike, Hewson and Herzog, 1982). Part of the conceptual reorganization is to give up the notion that heat has intensity or hotness, and to acquire the notion of amount of heat.

TRADITIONAL VERSUS MBL TEACHING OF THERMAL PHYSICS

To help students differentiate heat and temperature, it is important to demonstrate to them that they are different physical entities whose relation is not a simple linear function. Traditional lab activities focus on cooling curves, latent heat, and specific heat. But those demonstrations will be more effective on a student who already has some sense of the distinction, who knows there is a difference although he/she might not be clear about distinguishing properties. For most students however, it is not a matter of not being clear about the distinction; they firmly believe that there is no distinction between heat and temperature. Trying to interpret a demonstration within their own framework, they will distort it and draw such conclusions as "0°C is as cold as ice can get" or "Alcohol heats up faster than water because it is less dense." This is the Catch 22 of thermal physics instruction: in order to understand the activities demonstrating that heat is different from temperature, one needs to differentiate heat and temperture to begin with.

The same is true of heat and temperature measurements. Students are told that amount of heat is measured with a calorimeter. Unfortunately, to measure heat with a calorimeter one measures temperature and has to perform computations involving the mathematical relation among temperature, heat, mass and specific heat, a relation that is based on the very distinction that the students lack. In other words, calorimeters do not give *direct phenomenological access* to the concept of amount of heat, and they do reinforce the misconception that heat is measured with a thermometer. Thus, *amount of heat* remains a very abstract concept, remote from immediate experience, and unlikely to displace the very well entrenched notion that the measure of heat is its temperature and thus that heat is an intensive variable.

In contrast to traditional laboratory methods, Microcomputer Based Laboratories (MBL) give users direct access to the concept of amount of heat and visually demonstrate that heat and temperature are not always correlated. In a Microcomputer Based Lab, the microcomputer is used as a laboratory base for student directed data acquisition, display and analysis. In our studies, students use heat pulse generators--which we refer to as "heat dollopers" during the teaching interventions--to heat up and melt substances, and thermal probes to record temperature. Both are connected to the game controller port of an Apple II computer. The software allows the students to display graphs of temperature varying in real time (as recorded by the thermal probe). Also appearing on the graph are all the heat "dollops" as they are being delivered (Fig.1). The student can watch the temperature changes as a function of the heat pulses being delivered.

Thus, the MBL hardware and software give the student direct phenomenological access to a measure of heat which is independent of the measure of temperature. Moreover, the software emphasizes visually the distinction between heat and temperature (graph and arrows) and directly shows that quantitative relations between heat and temperature exist (when heating liquids, e.g., each dollop causes a fixed step in the temperature curve which is inversely related to the quantity being heated and depends on the nature of the liquid) and that the relation is different during phase change (temperature stays constant). As long as they accept that the curve is a temperature curve while the number of dollops is a measure of heat, the students can "see" that heat and temperature are different entities with minimal inferential processing. Students who make those rudimentary distinctions may then be able to interpret the specific and latent heat demonstrations correctly. The information given in these demonstrations would in turn enrich their concepts of heat and temperature and consolidate the differentiation. In other words it was hoped that the MBL lessons would trigger the reorganization of the students' thermal beliefs.

THE 1985 CLASSROOM STUDY

In the Spring 1985, we conducted a study at Newton North High School. Six ninth-grade classrooms were involved. They were divided into a "computer group" and a "control group." Both groups were taught the same content material for the same amount of time (two-and-a-half weeks). The topics were selected among those in the regular ninth-grade science curriculum: the quantitative relation between heat and temperature (Lesson 1), specific heat (Lesson 2), cooling curves (Lesson 3) and latent heat (Lesson 4). Each topic illustrates differences between heat and temperature. The computer group received MBL instruction while the control group received traditional instruction. We predicted that the computer group would learn the Heat and Temperature curriculum better than the control group because the MBL instruction would help them reject the belief that temperature measures heat and to understand the difference between heat and temperature. A detailed account of this study can be found in the Heat and Temperature 1985 Technical Report (Wiser, 1985, ETC Report #TR85-17).

Two evaluation methods were used: an in-class test, administered to all students, and a verbal interview, administered to thirty-five students (eighteen from the control group and seventeen from the computer group) on a one-to-one basis. Both were administered before and after the teaching intervention. The in-class test was a set of 12 "quantitative," multiple-choice problems of the kind generally posed in science class tests (see Appendix 1). The interview explored thermal concepts and beliefs in an open-ended way (see Appendix 2).

QUANTITATIVE PROBLEMS TEST RESULTS

The results of the multiple-choice, quantitative problems test are discussed in detail in the Heat and Temperature1985 Technical Report. They show modest overall progress in both groups, with a small but significant advantage for the computer group. When the questions are analyzed separately, it becomes clear that progress was not uniform across questions. The computer group was far superior to the control group at answering questions about the quantitative relation between heat, temperature and quantity of substance. Students in this group reached ceiling for the easier questions. Progress was significant, but less dramatic, with no significant difference between groups, for the questions dealing with cooling curves and freezing points.

The specific heat questions yielded interesting results. The students learned about specific heat on two occasions. In one of the Heat and Temperature lab activities, they saw that, when the same amount of heat is given to equal masses of water and alcohol, the temperature of the alcohol increases more. In the Specific Heat lab activity, they heated equal masses of iron and aluminum to 100°C, placed them in identical cold water baths and saw that the aluminum made the water hotter. They were told that some substances (water, aluminum) have a higher storage capacity, or higher specific heat, than others (alcohol, iron). It takes more heat to raise the temperature of a higher specific heat substance by a certain number of degrees than to raise the temperature of the same amount of a lower specific heat substance by the same number of degrees. Conversely, when a substance with a high specific heat cools down, it releases more heat than when the same amount of a low specific heat substance cools down by the same number of degrees. That is because it has more heat "in store." The object of both labs was to dispel the notion that temperature is the measure of heat: the same amount of heat causes different temperature changes and objects at the same initial temperature release different amounts of heat.

Let us look at the students' performance on the questions related to specific heat. One question (Question 7) was probing the very content of the Specific Heat lab (about iron and aluminum). Both groups made significant, and equivalent, progress. This turns out to be very superficial learning however, given their poor performance on the other two questions, Question 5 (see Table 1a) and Question 6 (see Table 1b). In Questions 5 and 6, students were told that equal masses of gold and rubber (substances they had not studied in the lab) were given the same amount of heat. The temperature of the gold increased more than that of the rubber. The two masses were then placed in identical cold water baths. The questions were: "Which, of gold or rubber, has a higher specific heat?" (Answer: rubber.) And "Will one make the water bath hotter than the other?" (Answer: The water temperature will be the same.[1]) Question 5 was a transposition of the Water/Alcohol activity and Question 6 was a harder version of the Iron/Aluminum experiment.

The modal answer to Question 5, in both pretest and posttest, was that gold had a higher specific heat. Some students (21% in the computer group and 15% in the control group) switched from that answer in the pretest to the correct answer in the posttest but a large majority (70% in the computer group and 80% in the control group) stayed with the "Gold has a higher specific heat than rubber" answer. Of the students who chose the "Can't tell" answer in the pretest (an appropriate choice since they had not yet learned about specific heat), the majority switched to the "Gold" answer also, with only four students from the computer group (6%) and no one from the control group choosing the correct answer.

These results can be interpreted in the light of the conceptual framework the students bring to the classroom and of the interaction between new information and that initial framework. What sense can a student make of the Alcohol/Water demonstration without giving up the belief that temperature measures heat? If the alcohol gets hotter, it must be that it absorbs more heat. Their mechanical model for heating makes it easy for the students to accept that different substances react differently to heat: Denser substances "resist" heat more than ligher ones. So, for most students, the point of the Alcohol/Water lesson was lost; instead of learning that the same amount of heat causes different temperature rises in different substances, they "learned" that different substances absorb heat at different rates (which is of course true, but not the point). The students' posttest answers support such an interpretation: The gold gets hotter, therefore it has a higher heat, therefore a higher specific heat. For the student, higher specific heat means "is able to absorb more heat from a given source." The term "specific heat" itself is a regrettably misleading abbreviation for "specific capacity for heat," and may contribute to the students' difficulties.

How did the students not see the conflict between their interpretation (alcohol absorbs more heat) and the fact that "same amount of heat" was emphasized in class and also mentioned in Question 5? It is because "same amount of heat is given" is interpreted as "same heat" or "same degree of heat is applied" (see the Conceptual Framework Section above). The lab activities in the control group did little to dispel this interpretation. The heaters used by the students applied the "same" heat to the two liquids but it was easy to imagine that one liquid absorbed more of it than the other. In the computer group, the heat was delivered in "dollops." This should have made it more obvious that the same amount of heat actually went into the liquids. The fact that the number of students who chose the correct answer in the posttest was significantly larger in the computer group may be attributed to their using the dolloper. But the fact that they were a minority demonstrates that it was not enough to override the preconceptions of most students.

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[1] In fact, the temperature of the bath containing the gold will be slightly higher. But we assumed that the reasoning leading to this conclusion was beyond our subjects' knowledge. This assumption is justified by the students' statements in class and during the interviews.

Another conflict may have struck the reader: According to their interpretation, the students should believe that alcohol has a higher specific heat than water, the reverse of what they were being told. The class discussions revealed that it was exactly what most students had learned, and the teacher was unable to convince them otherwise. And in the clinical interviews, analyzed below, most of the students who had something to say about water and alcohol either said that alcohol gets hotter because it has a higher specific heat or they had distorted the empirical evidence to fit rote learned knowledge into their framework and said that water would get hotter because it has a higher specific heat.

The answers to Question 6 reveal more distortions. Question 6 shows a dramatic regression from pretest to posttest, in both groups.

In the pretest, half the students focused on the fact that the gold piece was hotter, concluding that it would make the water hotter. The other half chose the correct answer, presumably because they chose to ignore the temperature difference mentioned in Question 5 and focused instead on "same [amount of] heat." If the two pieces have the same heat, they will have the same effect on the water. But, in the posttest, many changed their mind and decided that the gold piece would make the water hotter, presumably because they misapplied the Specific Heat lesson. Question 6 evoked the Iron/Aluminum activity which showed that a substance with a higher specific heat made the water hotter. This piece of information fitted well into their preexisting schema; it reinforced the core belief that higher heat means higher temperature and vice versa. Having decided that gold has a higher specific heat than rubber, it was easy for them to conclude that it would make the water hotter.

This interpretation admittedly goes beyond the data discussed here; but it is strongly substantiated by the content of the interviews presented below. The students' failure at learning the correct information is a direct consequence of a deeply held misconception--that temperature measures heat-- and demonstrates a point made repeatedly in the education literature--that new information is assimilated into the students' framework, rather than displacing it, and is distorted in the process.

Thus the Specific Heat lesson appears to have communicated the appropriate concept to only a minority of students. The others simply "learned" that some substances absorb and release more heat than others, ignoring the crucial component of specific heat: "It takes different amounts of heat to raise the temperature of equal amounts of different substances by the same number of degrees." It also appears that the lesson failed to drive the differentiation between heat and temperature.

CLINICAL INTERVIEW RESULTS

The clinical interview was administered individually. It took approximately an hour. The experimenter asked a series of questions about dilation, equilibrium, the difference between heat and temperature, specific heat, and cooling and freezing, in the context of two demonstrations performed in front of the student. In the first demonstration, a flask of alcohol was placed in a hot water bath and the alcohol level was seen rising. The flask was removed before the level stopped. In the second demonstration, the same flask was placed in a water/ice mixture and a thermometer was put into the alcohol. Again the flask was removed before the temperature stabilized. The experimenter asked follow-up questions either to clarify statements or to challenge the student. See Appendix 3 for an example.

The results from the questions about heat will be presented here. We will discuss in turn the students' understanding of thermal dilation, of thermal equilibrium and of the difference between heat and temperature.

THERMAL DILATION

Question 1: "Why does the level rise?"

The classification of the students' answers is presented in Appendix 4. The major categories were: "Molecule" argument ("The molecules move faster and need a place to go"), "Force" argument ("The heat pushes the level up") and "Other" (e.g. "The alcohol tries to escape from the heat" or "It starts boiling"). The answers in the "Other" category showed no understanding of thermal dilation. The "Force" arguments were mechanical and macroscopic: Since the level moves, something must be pushing on it. The "Molecule" arguments were divided into 4 subcategories, according to their degree of sophistication. Students in the first subcategory understood the molecular basis of heat transfer. The prototypical argument in the second subcategory was: "The molecules move faster because they receive energy; they occupy more space, therefore the level rises." Arguments in the third subcategory lacked the energy part of the argument. Finally, the arguments in the fourth subcategory were either very impoverished ("The molecules move faster") or were a direct analogy from the macroscopic event to the molecular one ("The molecules enlarge").

The four "Molecule" subcategories, together with the "Force" arguments and the "Other" answers form six levels of understanding of dilation. The pretest and posttest distributions are presented in Table 2.

Half the students (17 out of 35) progressed from pretest to posttest. The rest stayed in the same category, with only two students regressing. The number of "Molecule" arguments increased from pretest to posttest: Six out of the eight students who offered only "Force" or "Other" arguments in the pretest made a "Molecule" argument in the posttest. The number of "Force" arguments decreased from pretest to posttest, especially in the control group. Four out of 5 control group students, versus 6 out of 11 computer students, abandoned "Force" arguments from pre- to post-test. Finally the arguments relating the molecules moving faster to the fact they are receiving energy appeared only in the posttest (in 25% of the students: four computer and six control students).

Although half the students progressed, the numbers involved are too small to show significant differences between the two groups. One would not expect any, since the molecular model of thermal phenomena was presented in the same way to the two groups, after the laboratory activities were concluded. It is clear that a lot of the students come to classroom with the knowledge that "Heat makes molecules move faster," a notion that is taught earlier in the science curriculum. Those who do not arrive with this notion already in place acquire it easily. The link between increased motion and energy is also easily established by the students. They hear that heat is energy and it makes sense that energy make molecules move faster. What they do not understand, though, is that the energy involved in "Heat is energy" is the kinetic energy of the molecules themselves. Only one student described the heat exchange as a purely molecular process (the hot water molecules go faster than the alcohol molecules; when they hit the alcohol molecules, they make them move faster and the alcohol gets hotter[2]). For the other students, heat is an "opaque" concept; it is a special form of energy which is spontaneously emitted by the hot water. It has two distinct properties: it makes the alcohol molecules move faster and it makes them hotter. Many students try to relate the two further with a friction schema, linking what they know of the microscopic level with what they know of the macroscopic level: "The molecules move faster, they rub against each other and that generates heat."

To sum up: Accepting the idea that molecules move faster when a substance gets hotter poses no problem for the students. What they do not seem to assimilate is the symmetry involved in the process--that molecules move in both the alcohol and the hot water and that heat flows from the water to the alcohol because the water molecules have more energy. The students who learn that heat flows from hot to cold regions either do not know why it does or believe it is because there is less heat in cold regions and the heat "feels less crowded there."

THERMAL EQUILIBRIUM

Question 2: "Will the level stop?"

The modal answer is "No" in the pretest and "Yes" in the posttest. There is no difference between the two groups. See Table 3.

The answers to Question 2 are correlated with the students' understanding of thermal dilation, as expressed in Question 1. Whereas 50% of the students who used "Force" arguments (whether or not they also talked about molecules) in Question 1 said that the level would not stop, 75% who made only "Molecule" arguments in response to Question 1 thought it would. (In this analysis, the pretest and the posttest and the two groups have been combined because the results are similar.) One also finds that the probability of switching from "No" in the pretest to "Yes" in the posttest is a function of the level of understanding of thermal dilation in the pretest. Among those who said "No" in the pretest, all the students who were categorized at the higher levels for Question 1 (relating dilation to increased molecular motion) switched to "Yes" whereas only 60% of the students at the lower levels did.

Performance on the two questions may be correlated simply because they are both function of the students' general level of understanding of thermal phenomena, or more generally, of their physics knowledge. But a more interesting interpretation is that the students' concept of heat (as a force or as energy speeding up molecules) influences their concept of equilibrium. For example, if a student thinks of heat as applying a force on the alcohol level, she may tend to conclude that "As long as the water stays hot, it continues to apply a force and the level keeps rising." On the other hand, a student who understands that the water molecules are communicating energy to the alcohol molecules would tend to predict that the level will stop (when the molecules in the two liquids have the same energy).

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[2] The molecules do not necessarily move faster in a hotter substance, they have more kinetic energy. The distinction, crucial in physics, is not important here. Neither is the concept of average kinetic energy or average velocity.

Question 3 : "Why did the level stop?"

This question was asked to all students, whether they predicted that the level would stop or not. Those who predicted that it would not were asked "Suppose I told you it did stop. Why might that be?" The answers were analyzed with respect to the students' understanding of equilibrium (see Appendix 5). Thermal equilibrium, in physics textbooks, is described in the following way. When two bodies at different temperatures are in contact, heat flows from the hotter to the colder body until they reach the same temperature. Thus equilibrium has two components: the bodies end up at the same temperature and heat is exchanged until they do. The answers were analyzed accordingly. They were classified as providing evidence for the "equalization" component (the fact that temperature becomes equal), for the heat transfer component, for both, for neither (a "neutral" answer which is consistent with equilibrium but offers no positive evidence for it) and finally they could provide evidence that the student did not understand equilibrium.

Equilibrium here is taken in a broad sense; students were credited with the "equalization" component of equilibrium if they believed that the level would stop when some thermal variable is equal in the water and in the alcohol. That variable could be temperature, but also heat (e.g. "The level stops when the water and the alcohol have the same heat") or molecule speed (e.g. "It stops when the speed of the alcohol molecules is equal to the speed of the water molecules). They were credited with the "transfer" component of equilibrium if they mentioned that the level stops when "No more heat goes in" or "No more energy" goes in. Many answers were consistent with equilibrium but not sufficient evidence for it. For example, in "The molecules move at the same speed and do not need any more room", the student may have meant "at the same speed as the water molecules" but did not say so. Similarly, "There is a certain amount of heat in the water" is a very incomplete answer. Those were classified as "neutral." Finally, some answers showed that the student did not understand equilibrium (e.g. "It reaches a certain point, but I do not know what it is").

The results are presented in Table 4. There was no difference between the two groups. Five computer students (out of thirteen who were asked the question on both pretest and posttest) and seven control students (out of fifteen) made a better argument on the posttest. The data were then collapsed into two categories: "gave evidence for equilibrium" and "did not give evidence for equilibrium" (which includes "neutral" explanations as well as evidence against equilibrium). (See Table 5.) Thirty-three per cent (three out of nine) of the computer students and 44% (four out of nine) in the control group switched from "no evidence" to "evidence" for equilibrium.

One can compare students' answers to the first three questions. Not surprisingly, one finds a clearer understanding of thermal equilibrium (Question 3) among the students who predicted that the level would stop (Question 2) than among those who predicted it would not (96% versus 45%). More interestingly, all the students who achieved a complete understanding of equilibrium in the posttest (none did in the pretest) explained thermal dilation (Question 1) in molecular terms.

To sum up so far: As a whole, the students in both groups showed a better understanding in the posttest than in the pretest. There is no significant difference between the two groups; this is not surprising, since Questions 1-3 did not involve topics about which the instruction differed in the two groups.

Question 4: "If we pour more of the same hot water around the flask, will it affect the alcohol level?"

Question 5: "If we pour hotter water around the flask, will it affect the alcohol level?"

The answers to Questions 4 and 5 were analyzed with respect to evidence for or against equilibrium (see Appendix 6 and Appendix 7). In Question 4, answers could be supporting equilibrium ("The level will not rise because the added water is at the same temperature as the water bath" or "The level will not rise because the added water has the same heat"), be consistent with it ("The level will not rise"; no explanation), or be inconsistent with it ("The level will rise higher"; "The level will keep going"; "More hot water is hotter"). The proportion of correct answers ("The level will rise") increased similarly in both groups (from 61% to 75% correct predictions in the computer group and from 57% to 71% in the control group, among students who were asked the question). See Table 6.

Similarly in Question 5, the arguments could support equilibrium ("The level will rise higher until the alcohol has the same heat as the water"), be inconsistent with it ("The level will rise faster but not higher") or be inconclusive ("The level will go higher because there is more force to push it up"). Because most arguments were inconclusive (or "neutral") with respect to equilibrium, the answers to Questions 4 and 5 were combined. A student was categorized as showing an understanding of equilibrium if he/she was categorized as "Equilibrium" in both questions, or as "Equilibrium" in one question and "Neutral" on the other. Similarly, the student was categorized as "Non-equilibrium" if he/she was categorized as "Non-equilibrium" on both questions or as "Non-equilibrium" on one and "Neutral" on the other. The results are presented in Table 7. They show that relatively more computer than control students switched from "Non-equilibrium" in the pretest to "Equilibrium" in the posttest (5 out of 7 and 2 out of 7 respectively), although the numbers are too small to be reliable.

Finally, student's patterns of answers to Questions 2, 3, 4, and 5 were analyzed with respect to equilibrium. In the separate analyses described above for Questions 3, 4 and 5, the students' answers to Question 2 ("Will the level stop?") were ignored. In this way we could probe the knowledge of all students, including those whose intitial answer was incompatible with equilibrium. However the answer to Question 2 is essential to the diagnosis of equilibrium; consequently, in the present pattern analysis, students were credited with understanding equilibrium if they predicted that the level would stop, that more hot water would not make any difference and that hotter water would make it rise higher, and if they offered at least one "equalization" argument (i.e. mentioned that the level stops when either the temperature, the heat or the speed of the molecules are the same in the water and in the alcohol"). The results are presented in Table 8. Slightly more computer (40%) than control (30%) students progressed from no equilibrium in the pretest to equilibrium in the posttest.

Question 6: "If we set identical flasks of water and alcohol in the same water bath, will they reach the same temperature?"

The results are presented in Table 9. The modal answer in the pretest was "No" (63%). The reason most often invoked was that one of the liquid was less dense than the other one and absorbed the heat faster. The students who gave this answer were visualizing the heat pushing its way through the substance and "having an easier time" in the lighter substance. Another idea was that the water in the flask would reach the temperature of the hot water bath, because "they are both water", whereas the alcohol, being a different substance, would not.

Some students also thought that the alcohol would be harder to heat because it is harder to freeze. In the posttest, the modal answer was "Yes" (53%). Most of the students who justified their "No" answers (11 out of 13) referred to specific heat ("The water will get hotter because it has a higher specific heat"), whereas only 5 out of the 16 "Yes" answers mentioned specific heat ("They will reach the same temperature but the alcohol will get there faster because it has a higher heat storage"). This shows, again, the mis-assimilation of specific heat by most students. There was no significant difference between the two groups.

The high percentage of "No" answers shows the importance that kind of substance plays in the students' conceptualization of heating, but it is a different role from the one it plays in physics; in particular, it is inconsistent with thermal equilibrium. In physics, substances differ by their specific heat (the amount of heat necessary to raise the temperature of one gram of the substance by one degree C) and thermal conductivity (the amount of heat that flows through a substance in one second between two points one meter apart when the difference in temperature between the two points is one degree C). The rate at which two substances exchange heat is a function of both specific heat and thermal conductivity of both substances but also depends on the the temperature difference between the two substances. So that, no matter how fast the heat flows nor how much heat is exchanged, the exchange will stop when the two substances reach the same temperature. In contrast, the students think that heat absorption depends exclusively on the substance that is absorbing heat: some substances (generally lighter ones) absorb heat faster than others, in all circumstances. Moreover, for the students, temperature measures heat. They concluded that the alcohol absorbs heat faster and thus absorbs more heat than the water, and, consequently, it had to be hotter (in spite of the fact that both were in the same hot water bath). Unfortunately, the Specific Heat lesson reinforced those beliefs (see pp 9-12). Three students regressed from "Yes" in the pretest to "No" in the posttest; their posttest argument was: "The alcohol will not reach the temperature of the water because it has a lower specific heat than water, so it absorbs less heat [so, its temperature does not increase as much]." This phenomenon is important. It reveals a major distortion of information to fit it into the students' framework. For someone who believes that temperature is the measure of heat, the only way to interpret the Specific Heat Lesson is to conclude that some substances absorb more heat than others, and therefore become hotter when exposed to the same source of heat.

The students' answers to Questions 2 to 5 and to the Alcohol/Water question were compared to determine whether the same students showed or failed to show an understanding of equilibrium on both occasions. See Table 10. A third of the students (28% in the pretest and 38% in the posttest, with no significant group difference) were inconsistent: they demonstrated equilibrium in Questions 2-5 but not in the Alcohol/Water question ("YesNo" students) or the reverse ("NoYes" students). This shows that, for novices, thermal equilibrium is not the general principle that it is for physicists. The case of the "NoYes" students has several explanations. Some students may have developed or remembered equilbrium in the course of the interview (the Alcohol/Water question was asked at the end of the interview). Others were influenced by the fact that both flasks were sitting in the same bath; being both recipient of the heat given by the water, they should be affected in the same way ("It is the same heat"). In contrast, the equilibrium involved in Questions 2-5 was between source and recipient, which play asymmetrical roles in the students' conceptualization.

The case of the "YesNo" students confirms the analysis offered at the beginning of this section. The belief that some substances absorb more heat, and therefore get hotter than others, in all circumstances, conflicts with equilibrium, but students are more willing to give up equilibrium than to give up the concept that temperature measures heat.

What emerges from this analysis, together with the results of the multiple choice test, is that new information can create further misconceptions, rather than remedy the existing ones, because it is integrated into the students' alternative framework instead of replacing it. What also emerges is that, when a piece of information (e.g., equilibrium) is in contradiction with another piece (e.g., water absorbs more heat than alcohol), the students will not try to reconcile them, but will tend to reject the piece he/she is least attached to. This points to the need to help students with integration (by making them aware of these processes and giving them a framework in which the integration can take place), during classroom instruction, and with integrative homework questions. We will come back to this issue.

HEAT AND TEMPERATURE CONCEPTS

The main goal of the teaching intervention was to help students differentiate between heat and temperature. Their concepts were evaluated in two ways. First, we studied the ways in which they used the word "heat" in answer to Questions 1 to 6, to determine whether "heat" referred to an intensive quantity, measured in degrees, or to an extensive quantitaty, fundamentally different from temperature. Second, we analyzed the answers to two key questions: "If we fill a small beaker and a big beaker with the same hot water, does it make sense to say that one has more heat than the other, or do they have the same heat?[3] " (Question 7 or Beaker question) and "Suppose we hold two pieces of steel on the same hot plate for the same amount of time. They have the same cross-section but one is twice as high as the other. They are not left on the hot plate long enough to become very hot. If we have a thermometer in each piece of steel, will they read the same? Then we put them into two identical baths of cold water. If we have a thermometer in each water bath, will they read the same?" (Question 8 or Steel question). We will present the analysis of these two questions which probe in different ways the students' understanding of the extensive nature of heat. The Beaker Question is a direct probe. The Steel Question is indirect. It tests the students' ability to conceive of *amount of heat* (the two pieces receive the same amount of heat[4]), and to relate amount of heat, mass and temperature (the small piece of steel is hotter because the same amount of heat goes into a smaller mass; both pieces of steel raise the temperature of the water bath by the same number of degrees because they lose the same amount of heat). The first analysis (of the contexts in which students students used the words "heat" and "temperature") will not be reported here; its results correlate highly with the results of the Beaker and Steel questions.

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[3] Strictly speaking, it is incorrect to talk about the amount of heat contained in a substance, one should talk about amount of heat given off by a substance; as with other questions however (see questions about specific heat discussed on p10, we thought that the distinction between heat "given off" and "heat contained", although important in physics, would not be part of even the most advanced students' knowledge and that the students who understood the extensive nature of heat would answer that the two beakers contained different amount of heat. The results of the interviews justified this assumption.

[4] Again, the two pieces do not receive exactly the same amount of heat because their temperature does not change at the same rate. However, we assumed such reasoning to be beyond even the most knowledgeable students' understanding. Their answers justified this assumption.

Question 7: Beaker question

The answers to the Beaker Question ranged from "heat as an intensive quantity" ("The two beakers have the same heat because they have the same temperature") to complete differentiation between heat and temperature, with clear understanding of the extensivity of heat ("There is more heat in the bigger beaker. There is more heat energy in the big beaker for transfer. If you have 20 Joules of energy in one cup, the temperature may be the same in two cups, even though two cups would have 40 Joules of energy" or "The bigger one has more heat because it has more molecules. They are the same temperature because it is the same distance between the molecules").

In between were answers showing that the student took volume into account, more or less successfully, and without achieving complete differentiation. The first intermediary stage is one of confusion, in which heat and temperature are completely undifferentiated . The student knew that volume mattered but had only the concept "heat-as-measured-by-temperature" to work with. Such a student would say: "The bigger one has more heat and it is hotter" (although it was made very clear that the two beakers were filled with the same water), or "The smaller one has more heat because the heat in it is more densely packed."

Other students first followed their intuition and said that the bigger beaker had more heat. But when the interviewer asked whether theirtemperature was the same, they said "Yes, so the heat is the same after all" or they vacillated between the two without being able to resolve the conflict. Finally, at the most advanced of the intermediary stages, the students thought that heat has two measures: degree and amount, so that the bigger beaker "has more of the same degree heat." All those intermediary students knew that heat has an extensive aspect but they would not give up the belief that temperature measures heat. See Appendix 8 for a list of categories.

The results are presented in Table 11. In the pretest, the modal answer in both groups (65% overall) was "Heat intensive." In the posttest, the majority of students (82% overall) had some notion of the extensivity of heat, 61% of the students (76% in the control group and 43% in the computer group) having progressed in their understanding of that notion. To simplify the analysis, the "Confused", "More heat, no explanation" and "Temperature and amount" categories were reduced to a single category: "Incomplete Differentiation." It was the modal category in the posttest for the computer group, whereas the majority of the control students fell into the "Differentiation" category. In fact, only control group students progressed to the "Differentiation" stage. The difference between the two groups will be addressed below (see Beaker and Steel Questions compared).

Of special interest is the fact that all but two of the students who showed differentiation in the posttest used a molecular model to explain the difference between heat and temperature (e.g., "The bigger one has more heat because it has more atoms moving around").

Question 8 : Steel question

The answers to the two steel questions were not simply classified as correct or not correct: The concepts used by the students to reach a solution were taken into account. The categories used, with examples of answers, are presented in Appendix 9. The rationale for this choice of categories is the following:

a) An answer was categorized as "Heat intensive", if the student never talked about heat as extensive (i.e. never mentioned "more heat" nor "amount of heat" in the extensive sense of "amount") and based both solutions on temperature. Some ignored volume entirely, predicting that the two pieces would reach the same temperature because they received the "same heat," and would have the same effect on the water baths because they were at the same temperature. Others took the volume of the steel pieces into account either in the first or the second part of the problem, or both, but only on intuitive grounds. For example, some students said that the two pieces would reach the same temperature because "they receive the same heat" but that the bigger one would make the water hotter because "it is in contact with more water." Others said that the smaller piece would be hotter, because "there is less of it to heat," drawing on their everyday experience that a small pot of water takes less time to heat than a big pot. The fact that they went on predicting that "the smaller piece will make the water hotter because it is hotter," thereby failing to take volume into account, shows that they thought of heat as intensive.

A few students predicted that "the water temperature may be the same because, although the bigger piece is less hot, it is bigger, so that the effects of the two [size and temperature] compensate." Although this prediction is correct, it is not based on a concept of heat differentiated from temperature; it does not make use of the concept "amount of heat" nor of its relation with mass and temperature. (An answer based on differentiated concepts would be: "Both pieces absorb and release the same amount of heat and consequently heat the baths in the same way. The smaller piece gets hotter because the heat is distributed among fewer molecules/in a smaller mass.") Instead, the students used a causal schema in which the effect of a heat source is a function of its intensity (temperature) and its area of contact with the recipient.

b) An answer was categorized as "Undifferentiated" if the student said: "The bigger piece absorbs more heat; it is hotter and makes the water hotter." Such a student takes volume into account but obviously fails to differentiate between heat and temperature.

c) Students who fell into the "Differentiation" category offered two types of solutions, which both demonstrated that they understood the difference and relation between heat and temperature. One type of solution was the correct one: Both pieces heat the water equally because they receive and release the same amount of heat. The smaller piece gets hotter because the same amount of heat is distributed within a smaller mass. The other type of solution resulted from a misunderstanding of the problem. Some students understood that the two pieces would be left long enough on the hot plate to reach equilibrium. Their answers were that the two pieces would reach the same temperature and that, in the process, the larger piece would absorb more heat and thus release more heat into the water bath. Differentiation is clearly expressed in statements such as "Once they reach the temperature [of the hot plate] they are going to stop going up. It takes less heat to get the small one to that temperature, so the big one will have more heat in it once it reaches that temperature. Once they get to it neither will absorb any more [heat] but while they were absorbing heat, the bigger one was taking more because it has more mass and volume so it needs more heat," or "They are at the same temperature because it is the same heat per volume." Students in this category appear to have an exclusively extensive concept of heat.

d)Students were categorized as "Incomplete differentiation" if the concept of heat underlying their solutions had both an extensive and an intensive aspects. In this category we find those who stated that heat has both degree (temperature) and amount. This "amount of heat" is very different from the physicist's concept: It is "amount of a certain degree heat." Such a concept does not allow, for example, to answer correctly "Is more heat available in a large container of warm water or in a small container of hot water?" because the "heats" in the two containers are not directly comparable, being of different degrees. Similarly students with this concept of heat could not solve the steel problem correctly. Instead, they answered that the two pieces would have the same temperature, because they received the same degree of heat, although the bigger piece absorbed more of it. They seemed to visualize the heat of the hot plate being applied to the two pieces and, "because there is more room in the big one, more heat can go in." Although leading to the same prediction, this underlying schema is very different from the reasoning of the students who mistakenly believed that the two pieces would be left long enough on the hot plate to be in thermal equilibrium with it. (Compare the answer "Incomplete differentiation C" with the answer "Differentiation B" in Appendix 9). The students were divided about the next prediction: Some thought that the bigger piece would make the water bath hotter because it released more heat, others thought that the two pieces would heat the baths equally because they released the "same [degree]" heat and still others vacillated between the two, evincing the conflict that this incompletely differentiated concept leads to.

A few students in the "Incomplete differentiation" category made still different predictions (the smaller one will be hotter and will make the water hotter, or the smaller one will be hotter and the two pieces will make the water baths equally hot) but their justifications evinced the same important conceptual characteristics as the others in this category. To predict that the small one would be hotter, they relied on the notion that the two pieces received the same amount of heat from the hot plate. But "same amount of heat" was used only in a situation in which sources at the same temperature applied heat for the same amount of time. The students could conceive of the heat being more "crammed" into the small piece, but not of two objects at different temperatures releasing the same amount of heat; consequently they predicted that the smaller piece would make the water hotter, because it was itself hotter, or hesitantly reached the conclusion that the effects on the water baths may be the same because "the bigger one is bigger but it is less hot, so it probably compensates."

To sum up, for the students in this category, "amount of heat" is a restricted concept, very different from the expert's, and the intensity of heat is still very much at the center of their conceptualization.

The results are presented in Table 12. More control than computer students showed progress (69% versus 47%). Few students (3 in the control group and 1 in the computer group) reached complete differentiation. The majority of those who were at the "Intensive" stage in the pretest moved to the "Nondifferentiation" or "Incomplete differentiation" stage. They had learned that bigger quantities of substance absorb more heat, but were not able to acquire the expert concept of amount of heat. Instead they became confused about the meaning of "hotter" or added an extensive aspect to a basically intensive concept. As in the Beaker Question, the control group is doing somewhat better.

Let us reiterate that both correct and incorrect predictions could be achieved both on the basis of an intensive or of an extensive concept of heat. (Compare the reasonings in a) and c)). Obviously, tabulating answers to problems simply as correct or incorrect is not enough for the diagnosis of conceptual systems, because the same answer is compatible with several different representational states.

Beaker and Steel Questions compared.

The Beaker and the Steel Questions both probe the differentiation of heat and temperature. Table 13 and Table 14 show that there is a strong correlation, both in the pretest and the posttest, between the types of answers given to the two questions. This validates the interview as a tool for probing students' conceptual systems. One notices that, in the posttest, students who were not at the same stage on both questions tended to be in a lower category for the Steel than for the Beaker question. This suggests a rote or poor assimilation of the difference between heat and temperature; in the applied context (the Steel question), students reverted to their own intuitive conceptualization. Tables 13 and 14 also show that students who simply stated "The bigger one has more heat" in answer to the Beaker Question, without offering any justification, had little understanding of heat extensivity, as evidenced by their poor performance on the Steel Questions.

What emerges from these results is that instruction was successful in instilling the notion that heat and temperature are somehow different, but not successful in making students understand in what ways. Many students learned that "the bigger one has more heat," but either concluded that "the bigger one is therefore hotter," or could not resolve the conflict of the bigger one having more heat and yet being at the same temperature (because they still believed that temperature is the measure of heat); or they applied this new notion indiscriminately (i.e. believed that, in any circumstances, larger masses have more heat, e.g. because there are more molecules moving). In other words, students learned that mass is relevant to heat, but did not acquire an autonomous concept "amount of heat," to be used in a flexible manner.

Table 11 showed that only control group students achieved differentiation on the Beaker Question. We now see that the differentiation was, for most students, superficial: it could not be successfully sustained in an applied situation. If one now grants "differentiation" only to students who demonstrated it in the Steel problems as well as in the Beaker question, the control group superiority becomes less overwhelming. Nevertheless, it does not disappear, and one has to wonder why no computer student reached a stage in which the differentiation between heat and temperature could be sustained. Another, perhaps less interesting question, is why the computer students did not even reach a stage of "superficial" differentiation. These questions are addressed below.

CONCLUSIONS FROM THE 1985 STUDY

The teaching intervention developed the students' ability at solving problems about heat and temperature (as assessed by the multiple-choice test) and their conceptualization of thermal phenomena (as assessed by the verbal interview). The computer group was significantly superior to the control group in the multiple-choice posttest but not in the post-interview.

The computer advantage on the multiple-choice test was discussed in detail in the 1985 Technical Report. The most likely reason for it is that the dolloper and the software gave students a better understanding of "unit of heat," which facilitated solving problems about the quantitative relations between heat, mass, and temperature. It also gave them a (modest) advantage on the specific heat questions. The key to understanding specific heat is, of course, to accept that two substances may receive the same amount of heat and yet undergo different temperature rises as a result. As was discussed on pp.5-6, most students were unwilling to give up the notion that temperature measures heat and reasoned instead that, if two substances undergo different temperature rises, one must be absorbing more heat than the other. Two factors may have contributed to helping some computer students avoid this misinterpretation: the visual display emphasizing that heat and temperature were not always correlated and the dolloping itself. Although both groups used the same heaters, the computer students delivered discrete dollops of heat; the fact that the same number of dollops was being put into the two substances may have made the notion that they were indeed absorbing the same amount of heat more "inescapable." In contrast, the control students were "applying heat" in a continuous fashion, much as if they had been using a hot plate. It may have been easier for them to imagine that one substance absorbed more of the applied heat than the other, and thus to stick to their preconceptions.

It is impossible to perform statistical tests on the results from the interviews because the numbers of students in each category are too small; thus many conclusions drawn from the interviews are to be taken as tentative, except for the general conclusion that, against our expectations, the computer group did not undergo a more complete conceptual reorganization than the control group.

The two groups appear equivalent in their understanding of thermal equilibrium. Progress on this topic seemed very much linked to the kinetic molecular model. Students who viewed dilation at the molecular level were more likely to believe in equilibrium (may be because they understood that dilation stops when the molecule energy is the same on both sides) than those who, for example, attributed the level rising to the force of the heat (because no symmetry is involved in this schema: There is no reason for the level to stop unless the force is removed).

A lot of students seemed to have learned that heat and temperature are different, and more specifically that, if two different masses of the same substance are at the same temperature, the piece with the greater mass has or releases more heat. However, most of those students did not acquire the expert concept "amount of heat": their core conceptualization was still one in which heat is measured in degrees. Such a concept is sufficient to understand that a bigger quantity of hot water has more heat than a smaller quantity but not to conceptualize situations in which amount of heat, temperature, and mass must be related in a more complex way.

The interviews demonstrate the power of initial misconceptions, and their resistance to change. Few students stopped believing that temperature measures heat. We saw that misconceptions limit the assimilation of new information (as in the case of amount of heat) and distort it (as in the case of specific heat), and that they can even worsen (as in the case of the students who gave up the notion of equilibrium because they misinterpreted specific heat).

Against our expectations, the control group students were much better at stating the difference between heat and temperature (superficial learning), and somewhat better at using it in an applied situation (a sign of deeper understanding). It may be that the teachers took more care in explaining the difference between heat and temperature in the control classes (see 1985 Report for a discussion of teachers' bias). It could also be that the computer students focused on the more technical aspects of the laboratory activities, which were novel, and devoted less time to concept learning. Alternatively, the control group's superiority may be related to the fact that more control students appeared to understand the kinetic molecular model.

In any case MBL instruction was not more effective than traditional teaching at inducing conceptual reorganization, although it helped students solve quantitative problems about heat and temperature, most probably because the "dollop" gave them a better understanding of a heat unit. It seems that we placed too much weight on the notion that MBL itself could drive the differentiation, by making the differences between heat and temperature more accessible to the students. In fact, most students are not capable of reorganizing their thermal beliefs on their own; more time and effort on the part of the teachers has to be devoted to helping students in that reorganization. Combined with an effective presentation of the textbook theory, MBL may then be found to be an effective tool in facilitating conceptual change.

In their presentations, teachers should take into account not only the students' preconceptions but their potential misinterpretations of the material. Discussing with them the results of studies such as this one should help them realize how easily experimental evidence meant to dispel a misconception gets distorted to fit into the students' framework. This study also shows that students need a great deal of help in integrating and qualifying the different aspects of thermal physics; for example, in reconciling thermal equilibrium with specific heat phenomena, or the fact that substances with higher specific heat get *less* hot when they receive a fixed amount of heat, but release *more* heat when they cool off, or in understanding that bigger objects do not *necessarily* absorb more heat.

We believe that giving the students a general framework, such as a kinetic molecular model, in which to integrate the different phenomena they are studying, would be extremely productive. A molecular model may also help them acquire the expert's concept of amount of heat, get a firmer grasp on specific heat by allowing them to understand why substances differ in specific heat, and understand the symmetry of heat flow. The fact that the students who achieved differentiation in this study, did so on the basis of a molecular model, and that progress in the understanding of thermal equilibrium is also linked to such a model, justifies developing computer simulations for the molecular kinetic theory.

The study we conducted in the Spring 1986 addressed these issues, except for the molecular model, on which we are presently working. It also used a written version of the verbal interview as an teaching assessment method.

THE DEVELOPMENT OF A WRITTEN VERSION OF THE VERBAL INTERVIEW

The clinical interviews proved invaluable in assessing the students' conceptualization. But administering them and especially analyzing them is extremely time consuming and requires well trained experimenters. We tried to simplify the procedure by developing a written version of the interview, which could be administered to entire classrooms at a time and be more easily coded and analysed. We tested the validity of this written, multiple-choice "interview" (to which we will refer to as the "multiple-choice conceptual test), by administering it to four classrooms. Students were randomly selected from those classrooms to be interviewed verbally and individually, either before or after taking the written test. Their answers to the verbal and to the written versions of the inerview were then compared.

We selected the main questions and prototypical answers from each category of answers given by the students both in the pre- and post-interviews from the Spring of 1985 classroom Study (see above). They probed the students' understanding of the extensivity of heat, the relation between heat and temperature, thermal dilation, thermal equilibrium, cold as the absence of heat, freezing points and specific heat. (See Appendix 10.) For each of the heat question, some choice answers were formulated in terms of heat-as- an-intensive-quantity, and some in terms of heat-as-an-extensive-quantity. For example, for the Beaker Question ("Suppose we have two different size beakers filled with hot water that was heated in the same pot. Which of the following is true about the situation:"), the possible answers included: "They have the same heat because they have the same temperature", "The bigger one has more heat and it is hotter", "They have the same heat but the bigger one has more energy", "There is more heat available in the big one becuse heat is proportional to mass" etc. Similarly, for the cold questions, some answers expressed the concept that cold is the absence of heat ("The temperature of a flask of alcohol placed in ice goes down because the ice absorbs the heat from the alcohol"), and others the concept that cold is an entity separate from heat ("The temperature of a flask of alcohol placed in ice goes down because the ice lets off coldness which goes into the alcohol.")

SUBJECTS

The subjects were students in two ninth-grade and two tenth-grade science classes at the Newton North High School. Letters were sent out to their parents asking for their permission to let their child participate in the individual interviews. Six students in each class were selected at random from those receiving parental permission to be interviewed verbally and individually.

PROCEDURE

The written multiple-choice conceptual test was administered in each classroom during one of the science classes. The students took between 20 and 30 minutes to complete it. They knew that they were participating in a research project and that their performance would not affect their science grade. They were told to choose as many answers as they liked for each question. This procedure was adopted because it would give us more information about the students' conceptualization, including contradictory beliefs, than if they had been forced to pick only the "best" answer.

Twelve students (three in each class) were interviewed individually before taking the written version of the test and the other twelve were interviewed afterwards. The verbal interview took place within a week of the written one.

ANALYSIS

The analysis was restricted to the students who had been interviewed. Its goal was to determine to what degree each student's answers in the verbal interview matched his/her choices in the written test. To that effect, the verbal answers to each question were categorized as matching one, several or none of the choices in the written test. A concordance coefficient was then computed for each student and each answer as: [number of matches-number of non-matches]/number of possible choices for that question. The individual concordance coefficients were then averaged across students for each question. The results are presented in Table 15.

The concordance between the two versions of the interview appears sufficient to justify using the written version as a large scale evaluation tool. The drawback of a multiple choice test is obvious: Students might "like" some answers when they see them that they would not have thought of themselves. They also probably pay less attention when answering a multiple-choice written test than when talking to an interviewer and the written choices cannot capture the richness of verbal answers, followed-up or challenged by the interviewer. Nevertheless the time saving factor, and thus the possibility of gathering data from more students, made us opt for the witten version , after a few changes to its format. Answers that had been chosen by very few students were deleted, answers written under "Other" were taken into account, answers that seemed, in retrospect, poorly formulated, were modified .

THE 1986 CLASSROOM STUDY

This study was conducted in the Spring of 1986. It was smaller scale than the previous one, incorporated new computer instruction material, and capitalized on the findings from the previous study for the design of the curriculum and the structure of the class discussions.

The lesson topics and MBL hardware and software were the same as in the Spring of1985 Study. The content of the computer lessons on specific and latent heat were modified and enriched. They included new MBL activities (e.g. delivering dollops into different substances, recording their temperatures, mixing them with cold water and recording the temperatures of the mixtures) and Computer Laboratory Simulations. Their purpose was to give students a more complete understanding of specific and latent heat and avoid some of the misinterpretations so prevalent in the 1985 Study.

In the revised computer version of the Specific Heat Lesson, we tried to convince students of the following. Assuming that substance A has a higher specific heat than substance B and that equal masses are involved, then:

a) If A and B are at the same high temperature and are placed in identical cold water baths, A will make the water hotter than B.

b)It takes more heat to bring A than B to a given temperature.

c)If the same amount of heat is delivered to A and B, A's temperature will be less high than B's.

d)If A and B are then dropped into identical cold water baths, the water temperature will be (almost[5]) the same.

The lab activities demonstrated a) through d) for several substances and the class discussions and homework emphasized the systematicity of the relationships between the four laws. These activities addressed the major misconceptions and misinpretations about specific heat we had found in the Spring of 1985 classroom Study (see pp. 5-6). For example, d) should help convince the students that, since the same amount of heat was released by A and B (as evidenced by the nearly identical water bath temperatures), the same amount had been absorbed in c). And the juxtaposition of a) and c) should force students to confront what is, for them, a paradox: that a substance with a higher specific heat can both get less hot (as in c)) and make other things hotter (as in a)). The lesson as a whole was intended to suggest a framework for specific heat, in terms of heat storage, and thus to help students differentiate between specific heat and heat, and between heat and temperature.

Similarly, the Cooling Curves Lesson contained more information than in the 1985 Study. It showed students not only that temperature stayed constant during freezing, but that a substance actually loses heat while freezing. This was done by using an alcohol bath, instead of a water bath, around the freezing liquid; alcohol has a much smaller specific heat than water, and thus its temperature is a more sensitive indicator of small heat losses or gains.

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[5] See footnote 1.

Those lesson plans were carried out using Computer Simulation Laboratory because they were too lengthy for hands-on experimentation and because they would be hard to perform with enough precision for the results to be convincing.

Finally, the researcher met frequently with the teacher during the study to talk about students' preconceptions, give him feedback about their understanding and misunderstanding of the material being presented and to help him plan classroom presentations and discussions.

HARDWARE AND SOFTWARE

The hardware and the MBL software were developed by Robert Tinker, at the Technical Education Research Centers (TERC) in Cambridge, Mass.. They had been used in the previous study. The Laboratory Simulation software was developed by George Martins, science teacher at the Newton North High School and was used for the first time in the present study.

HARDWARE

Temperatures are measured with thermistors. The thermistors have 100 KOhm nominal resistance at 25°C; they are manufactured by Fenwall Electronics. They are a glass bead type encased in shrunk wrapped tubing which provides protection against mechanical and thermal shock. The thermistor resistance is determined by using the Apple game paddle electronics which generates a signal while an internal capacitor is being charged to 5 Volts through the thermistor. A machine language software routine measures the time by counting iterations of a count and test loop. Calibration software converts this count to temperature with an overall accuracy of ± 1°C and a short term stability of less than .2°C. Calibration against a laboratory standard thermometer is required for this level of accuracy. This calibration was performed immediately prior to the classroom test. The two thermistors were designated Red and Blue and were distinguished electrically by being connected to two different game paddles input.

The heat is delivered with a standard 110AC immersion heater switched by a solid state relay. A 555 timer started by the user pressing a button switches the heater on for a fixed time delivering a dollop of heat. The software monitors a game connector push button line connected to the timer in order to determine how many times the heater is pulsed. The button must be pressed after the end of the previous pulse to start a new pulse.

The electronics were built into a black plastic box that connected to the game controller DB-9 connector at the rear of the Apple IIc or Apple IIe computer. The thermistors and the heater are connected tothe box.

MBL SOFTWARE

The MBL software used in this study is called the *Dollop* program. It is based on the idea that the computer and hardware should be used as a laboratory instrument and that the software should be designed to allow the student to gather data, to graph them in various ways, and to analyze and transform them.

The *Dollop* program is used in conjunction with a temperature probe and a heat dolloper. The computer graphs temperature as a function of time, prints temperature readings on the graph and records amounts of heat by placing an arrow right underneath the temperature curve everytime a dollop of heat is delivered. (See Fig.1 for an example of heat/temperature graph). A typical run goes as follows. The student types in the time during which he/she wants to collect data and the maximum and minimum temperatures that he/she expects. Two labelled axes (temperature/time) appear on the screen. The probe and heater are placed in the substance (generally a liquid) being studied. The student presses a key when ready to record. The temperature of the probe is graphed in real time. To heat the liquid the student presses the button on the heater box as many times as he/she wants dollops. The corresponding number of arrows appear on the screen, as well as a digital reading of the temperature just before and just after the heat was delivered.

When the graph is finished, the student can ask for the Table of Results which summarizes the data he/she just collected. The table displays the temperature increases for each quantity of heat that was delivered as well as the average temperature increase/dollop.

COMPUTER LABORATORY SIMULATION SOFTWARE

The Laboratory Simulation software was developed by George Martins, of the Newton North High School, Newton, Mass.. With Computer Laboratory Simulations entire experiments are performed on the screen. The role of the student is to choose an experiment, then the parameters in the experiment (e.g., quantities of liquids, initial temperatures) and to monitor its unfolding. On the screen a cartoon presents experimental manipulations (e.g., beakers being filled and poured into each other), data collection (e.g., a thermometer is put into a beaker), data recording (e.g., the temperature in a beaker continuously appears on the screen), data summarizing, graphs and tables.

This kind of activity deprives students from "real" laboratory experience, and should not, in our opinion, be used to the exclusion of the latter. But it offers significant advantages.

a) Use of hazardous or hard-to-work-with materials. Many substances have attractive physical properties (very high or very low specific heat, e.g.) but are either dangerous (mercury, ether) or messy (oil). Such substances pose no problem in a Computer Simulation Laboratory.

b) Elimination of experimental difficulties. In thermal physics (as in other areas, no doubt), it is difficult for high school students to collect "good" data. For example, distributing heat into a mass of sand or iron shavings take time, during which much heat is lost. Or, when using a cold alcohol bath to freeze a liquid, the alcohol receives ambient heat as well, so that its temperature does not reflect the latent heat realeased by the liquid. Moreover, the temperature plateau, during freezing, may be missed if the cooling bath is too cold, or may not be constant, if the freezing substance is not pure. Thus, the temperatures being recorded are often far from what they would be in a carefully controlled lab environment. But, often, the force of the experimental evidence depends crucially on accurate results. For example, in d) above, the temperatures must really be almost equal in order to convince the students that the same amounts of heat were released. And they have to believe the same amount of heat was released (in spite of very different initial temperatures) in order to be led to reject the notion that temperature measures heat. Similarly, the temperature plateau in a freezing liquid must be horizontal for students to believe that temperature stays constant during phase changes, and there must be no doubt that the increasing temperature in the bath is due to heat from the liquid. Computer Simulation Laboratory avoids all these experimental problems and thus helps make the experimental evidence more convincing.

c)Time saving. Because Computer Simulation Laboratory experiments are much faster to run than the real thing, many more experimental situations can be explored in a fixed amount of time.

In our study, we combined MBL with Computer Simulation Laboratory. The students first performed an MBL experiment, and then several similar experiments using Computer Simulation Laboratory. This combined the advantages of both laboratory activites: MBL gave them hands-on experience, and a sense of what the Computer Simulation Laboratory would be like if they were performed with real substances and instrumentation.

Computer Laboratory Simulation for Specific Heat.

In this simulation, students experiment with four substances with very different specific heats: water, sand, oil and mercury. Two heat dollops are delivered to one of the substances, and the final temperature is shown on the screen. The substance is then mixed with water, and the temperature of the mixture is shown. The experiment is repeated with equal masses of the other substances.

In a second series of experiments, the students are asked to deliver as many dollops as necessary to raise the temperature of the four substances by the same number of degrees. The heated substances are then mixed with water, and the final temperatures of the mixtures are shown. (See Fig. 2.)

Computer Laboratory Simulation for Cooling Curves.

In this simulation, a water sample is placed in a very cold ($-10^\circ C$) alcohol bath. The temperatures of the sample and of the bath are continuously displayed both digitally and graphically. (See Fig.3.) The student observes the concurrent cooling of the water and heating of the bath. It is quite clear graphically that, during freezing, the temperature of the water stays constant while the bath temperature continue to increase, and that the ice temperature continues to drop until it is in equilibrium with the alcohol. The Simulation should contribute to dispel the following misconceptions. Most students do not believe that temperature stays constant during freezing (because the bath is continuously applying cold). If they do accept that fact, they take it to imply that no heat or cold is being exchanged (because temperature measures heat and cold). For some students, it also implies that the freezing point is "as cold as a substance can get." Finally, they attribute freezing to cold being applied, rather than heat being removed, by the bath.

STUDENTS AND TEACHERS

Two ninth grade classes, of 23 students each, participated in the study. They had the same science teacher. The students' parents received a letter explaining the nature and goals of the study and a consent form. All parents agreed to let their children participate. One class was assigned at random to be the "computer group" and the other to be the "control group". The students were not told about this assignment. Since they initially all used the computers for the *Slalom Game* , they all were under the impression that they were participating in a "computer study." This impression was not dispelled by the teacher. This was meant to control for a possible Hawthorne effect. (Although we have all reasons to believe that the computer advantage found in the 1985 Study had a different origin. See the 1985 Technical Report.)

EVALUATION TOOLS

We used two evaluations, both administered in class right before and again right after the teaching intervention. One consisted of 20 quantitative problems with multiple-choice answers. Those problems were directly related to the content of the teaching intervention. Some probed the very situations of the laboratory activities (same materials, same values for some physical variables), others tested the same knowledge applied to novel instances. (See Appendix 11.) The other evaluation tool was the conceptual test discussed above, which was broader in scope. It explored students' understanding of the difference between heat and temperature in various ways. (See Appendix 12.) Most of the questions were not directly related to the content of the laboratory activities : It was designed to see whether students could use their new knowledge about heat and temperature to explain phenomena not dealt with in class, phenomena which "give trouble" to novices with an undifferentiated thermal concept.

CONCEPTUAL TEST

The second version of the written interview was used. It consisted of 19 questions about heat, cold and temperature. As explained above, the multiple choice answers were prototypical answers given by the students who were interviewed verbally in a previous study.

The testing session started with a demonstration performed by the teacher in front of the class. A flask containing colored alcohol was placed in a bath of hot water. The level rose but the flask was removed from the bath before the level stopped. Questions 1 to 8 probed the students' understanding of thermal equilibirum as well as their concept of heat: "Do you think the level of alcohol will stop rising up the tube?", "Why does/does'nt the level stop?", "Would more of the same temperature water around the flask change the level?", "Would hotter water make the level rise?". At issue is whether the student is going to use a force argument ("[The level stops] because the heat has limited force"), an intrinsic limit argument ("[Hotter water will not change the level] because the alcohol is already as hot as it can be"), or a thermal equilibrium argument ("[The level stops when] the alcohol and the water are at the same temperature"). Also at issue is whether he/she is thinking of heat in intensive or extensive terms. The students who predicted that more of the same hot water would not make a difference were asked whether 2 cups of hot water melt more snow than 1 cup and those who said "Yes" to this question were then asked to explain why more water sometimes has more effect (on snow) and sometimes not (around the flask)[6] . The resolution of this apparent paradox requires an understanding of thermal equilbrium, and of the fact that 2 cups of hot water gives off twice as much heat when melting snow, but are at the same temperature as 1 cup.

Questions 9 to 13 probed the understanding of the relation between heat, mass and temperature. Question 14 was about specific heat.

Questions 15 to 19 were about cold and freezing points: Do the students know that cold is the absence of heat, that temperature stays constant when a substance freezes, that a substance can get colder than its freezing point?

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[6] Those who thought that more hot water would make the level rise higher were instructed to skip these questions.

QUANTITATIVE PROBLEMS TEST

The test consisted of 20 questions: 9 questions about the relation between heat, mass and temperature, 3 questions about specific heat, 3 questions about phase change, and 2 questions about calories. The test also included a question about graph reading, to determine whether the control group would be at an advantage or disadvantage because they had drawn their own graphs. Finally one question asked directly about the difference between heat and temperature, and another one about the effect of heat on molecules. (See Appendix 11.)

PROCEDURE

About two weeks were devoted to the study. There were four 50-minute sessions a week. During the first two days, the students were given the two pretests (which took about 20 and 30 minutes respectively); they were told that the tests were not part of their grade, that it was information for the researchers and that they were not expected to know all the answers. They practiced with the apparatus to be used during the laboratory activities; the topic of heat and temperature was introduced.

Three lessons were taught: Heat and Temperature, Heat Storage and Latent Heat. Each took about two periods. The content of the lab activities was the same in the two groups except for the Heat Storage lesson (see below). The students received lab sheets describing the topic and goal of the lesson and the steps to be carried out in each lab activity. The lab sheets also contained tables to fill out with data and a series of questions as homework. The lab sheets for the computer and the control group were identical except, of course, for instructions (and specific lab activites about Heat Storage). While the computer group used the computers, heat dollopers and thermal probes, the control group used thermometers and resistance heaters. Those heaters were the same as those used by the computer group but were plugged in and out of wall outlets instead of being triggered by pressing a button. The amount of heat being delivered was measured by the number of seconds the heaters stayed plugged in. Another difference between the two groups was the heat temperature graphs. The students in the computer group saw the graphs on the screen and copied them. The graphs were temperature/time graphs with arrows superimposed on the temperature curve to indicate heat dollops. The students in the control group had to construct their graphs themselves from the data they had collected. Those graphs represented temperature as a function of heat in the Heat and Temperature lesson, and temperature as a function of time in the Latent Heat lesson.

Two other topics were briefly introduced. The students were told about Cooling Curves but did not perform any hands-on experiments. The computer group used a Computer Laboratory Simulation (see above: Computer Simulation for Cooling Curves) while the blackboard was used for the control group. The students were also introduced to the kinetic molecular model of heat and temperature. The computer group watched a computer model developed by Prof. R.H. Good, Department of Physics, California State University at Haywood. It represents the kinetic behavior of a container of gas molecules. There are two kinds of molecules, big ones and small ones, and their initial speed can be fast or slow. The molecules collide and exchange momentum and energy, and the velocity distribution changes accordingly. The control group were presented the same information on the blackboard.

All the class discussions were tape-recorded and later transcribed.

At the end of the teaching intervention the two posttests were administered. The students knew that the quantitative problems test was now relevant to their science grade.

LESSON PLANS

LESSON 1: HEAT AND TEMPERATURE

The topic of Lesson 1 was the quantitative relations between heat input, mass of substance being heated and temperature change, as well as the quantitative dependence of temperature change upon the kind of substance being heated. It was intended to give the students a sense of *amount of heat*, and to demonstrate that the same amount of heat can have different effects on the temperature of substances. Thus temperature changes should be viewed as caused by heat input, but not as the measure of heat: other variables are involved in the relation between the two. Heat is measured in dollops, it does not "carry its own degree or temperature."

The students delivered increasing amounts of heat to different amounts of water and alcohol. They recorded the temperature changes after each heat input. The aim of this lesson was to show that temperature increase is directly proportional to the amount of heat delivered to the liquid and inversely proportional to the amount of liquid. Temperature increase is also larger for alcohol than for water, given identical masses and heat input. The students were introduced to the concept of specific heat: The specific heat of water is greater than the specific heat of alcohol because more heat is needed to raise the temperature of a certain quantity fo water than the temperature of the same quantity of alcohol by the same number of degrees.

The lab sheets handed out to each group are found in Appendix 13 and Appendix 14. They give the details of the activities performed by the students.

LESSON 2: HEAT STORAGE CAPACITY

The topic of Lesson 2 was heat storage capacity (specific heat): Equal masses of different substances absorb and release different amounts of heat when their temperature increases or decreases by the same number of degrees.

The homework and class discussions in both groups took into account the difficulties experienced by students in the previous study and were designed to help them acquire a more correct view of specific heat.

Lesson 2 for the computer group.

See Appendix 15. It consisted of two parts--a hands-on MBL activity, using the Dollop program, and several Laboratory Simulations that extended the lab activity. In the MBL activity the students delivered the same number of dollops to the same masses of aluminum beads and lead shots (200g). They recorded the temperature rises, noting that they were different (Experiment 1). They repeated this experiment, using the Laboratory Simulation, on samples of oil, mercury, sand and water. After being heated, each sample was mixed with the same quantity of water and the final temperature recorded (Experiment 2). The third experiment, carried out also with the Laboratory Simulation, was a variant of the second one: one dollop was delivered to the mercury and then as many dollops as were needed to bring the other samples to the same final temperature as the mercury. Again, the samples were mixed with water and the final temperature recorded (Experiment 3).

We know from the Spring of 1985 classroom Study that students tend to misinterpret the outcome of experiments such as Experiment 1 and 2; they believe that the substance that gets hotter (here, the lead in Experiment 1 and the mercury in Experiment 2), absorbs more heat, and therefore must have a higher specific heat. We hoped to dispel this misconception with the third experiment, showing that mercury is the one that needs the least amount of heat to rise by a certain number of degrees, while water needs the most. The mixing demonstrations should reinforce the correct interpretation. In Experiment 2, all the substances have (more or less) the same effect on the water, although they have very different initial temperatures, thus they must really have absorbed the same amount of heat. In Experiment 3, they have very different effects on the water, although they have the same temperature before mixing; the water sample is the one that releases the most heat, therefore it must really have absorbed much more heat than the other samples, to reach the same temperature.

Those activites could not be duplicated with the control group because they would have been too time-consuming (with the Laboratory Simulations, a lot of samples can be tried in a very short time). More importantly, such experiments lead to huge experimental errors because of heat losses; it is also impossible to find four substances that are very different in specific heat, non toxic and not messy! Thus the lesson for the control group was the same as in the Spring of1985 Study.

Lesson 2 for the control group.

See Appendix 11. Three blocks of metal were used: a 50g block of iron, a 50g block of aluminum ("large aluminum"), and a 17g block of aluminum the same size as the block of iron ("small aluminum"). They were placed in boiling water long enough to reach 100^{o}C. Each block in turn was dropped in a cup containing room temperature water and the final temperature in the cup was recorded. The students saw that a mass of aluminum makes the water bath hotter than an equal mass of iron and had to infer that aluminum gives off more heat than iron when it cools off, although their initial temperature was the same.

We expected the students to argue that the large aluminum block made the water hotter because it was bigger; according to the novices' causal reasoning, a heat source has more effect when its surface of contact with the recipient is larger. This was the reason for using the small aluminum block: although the same size as the iron block, it made the water hotter. Therefore the different amounts of heat released by the different blocks depend on the material the blocks are made out of, not just their mass or their volume.

Like the computer lesson, this lesson was intended to demonstrate that heat sources at the same initial temperature and of either the same size or the same mass can provide different amounts of heat and thus to dispel the novices' schema of the effect of a heat source being a function of its intensity (i.e. its temperature) and its area of contact with the object it is heating. But we expected to be less efficient than the computer lesson in helping students revise their ideas, because it contained less information, did not challenge other misconceptions and did not provide a complete framework for the specific heat phenomena.

LESSON 3: LATENT HEAT

The students half-filled a beaker with tap water and measured its temperature. They added 1/2 cup or crushed ice and measured the temperature several time. When the temperature levelled off (at 0°C) they added another 1/2 cup of ice. The temperature did not change. They heated the ice/water mixture, recording the temperature at regular intervals until all the ice was melted. They went on heating the water for a while and recording its temperature. They observed that the temperature of the ice/water mixture stayed constant as long as there was some ice left but started increasing as soon as all the ice was melted.

The aim was to give the students the notions of fixed point and latent heat of fusion (the heat that is used to melt the ice without raising the temperature of the ice/water mixture). It was meant to dispel the misconception that adding heat necessarily raises temperature. It also showed that adding ice to ice/water mixture does not necessarily make it cooler, thereby dispelling another prevalent misconception (based on the fact that two ice cubes make a drink colder than one).

Lesson 3 for the computer group.

See Appendix 12. The Dollop program was used to record the temperature of the water and ice/water mixture. The heat dolloper was used to melt the ice. The students delivered dollops in quick succession. No record was kept of the number of dollops. The focus of this lesson was the contrast between the temperature plateau and the large number of arrows on the graph.

Lesson 3 for the control group.

See Appendix 13. The students used the heaters to melt the ice. The heaters stayed plugged in until the ice was melted and the water warm.

RESULTS: QUANTITATIVE PROBLEMS TEST

We will divide the analysis into several sections: the quantitative relation between heat, mass and temperature, specific heat, latent heat, cooling curves, calorie and "other". See Table 16 for detailed results and Table 17 for a summary.

HEAT, TEMPERATURE AND MASS(Questions 1, 3, 16, 18 and 19)

The students performed differently on different questions. Questions 1 and 3 were phrased in the terms used in Lesson 1 (a certain number of units of heat is put into a certain mass expressed in grams). Questions 16 and 18 were similar except that a novel context was used (hot plates); "unit of heat" was not mentioned. Moreover Questions 1 and 18, which involved inverse reasoning[7], were easier than Questions 3 and 16, which involved proportional reasoning.

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[7] "Proportional" and "inverse" reasoning are terms used by Strauss in his research on children's understanding of intensive and extensive variables. "Inverse" reasoning involves the same quantity of heat, e.g., being put into different quantities of water, whereas "proportional" reasoning involves different quantities of heat into different quantities of water. The task in each case is to predict the final temperature. He found that the development of proportional reasoning lags behind the development of inverse reasoning (Strauss, Stavy and Orpaz, 1977).

The computer students progressed significantly from pre- to post-test on both Questions 1 and 3. The control students progressed only on Question 1, and less so than the computer students, showing a limited understanding of the relation between heat, mass and temperature, even in familiar contexts. This result confirms our previous findings. Learning about the relation between heat, mass and temperature is facilitated by MBL training, presumably because the dolloper gives a better understanding of "unit of heat". Such an understanding is particularly useful to solve more difficult problems. However the computer students were not able to generalize their newly acquired expertise to novel contexts. On Questions 16 and 18, there was no difference in the progress (Question 18) or lack thereof (Question 16) between the two groups. This could be remedied by explicitly telling students that any source of heat delivers units of heat and by teaching them the laws of heat exchange.

The modal wrong answer to Question 1 is consistent with the preconception that temperature measures heat. Question1 states that the "same quantity of heat" is put into 100g and 200g of water. A third of the students answered that the final temperature of the two samples would be the same; in all likelihood, they reasoned: "same [quantity of] heat, therefore same temperature".

Question 19 confirms several of the points above. Like Questions 16 and 18, it asked about the relation between heat, mass and temperature in a novel context: the mass of the source, rather than of the recipient, was the one to vary. Again, no progress was made in either group. And, again, the modal wrong answer was that the two different masses of steel would raise the temperature of the (identical) water baths by the same number of degrees: Since they are at the same temperature, they give out the same heat and therefore have the same effect.

SPECIFIC HEAT (Questions 2, 5, 6, 7)

The information provided by the teacher and the lab sheets in this lesson was more explicit and complete than in the Spring of1985 classroom Study, and was meant to prevent some of the misinterpretations prevalent among the "1985" students. Those modifications paid off: Students in both groups made great progress on Question 2 (familiar substances) and Question 5 (unfamiliar substances), a result radically different from the previous year. Students here appear to have understood that temperature increases less, not more, in a substance with high specific heat.

We also predicted that the Computer Laboratory Simulations would help the computer group students relate the role of specific heat in heating and cooling processes, and thus understand the concept of specific heat itself better. The results (Question 6) were encouraging. The computer group performed significantly better than the control group in the posttest although progress was small. Obviously, the belief that a hotter substance has to raise the temperature of a cold bath higher, irrespective of that substance's specific heat, is very difficult to eradicate. But the success of the CSL becomes much more striking when the multiple-choice (quantitative problems) test results for the 1985 and the 1986 studies are compared. On Question 6, the computer group went from regress in 1985 to progress in 1986, while the control group regressed in both studies.

We believe that, by enriching the Lab Simulations and the class discussions, more significant progress could be achieved. For example, the students lacked an important notion--that if a substance requires X units of heat to go from 10°C to 20°C, it will release X units of heat when it cools from 20°C to 10°C. Adding activities related to this concept is easy to do with the

Lab Simulations; it would very probably facilitate learning not only of specific heat but of other topics such as latent heat and cooling curves (see below).

LATENT HEAT (Questions 10 and 12)

Question 10 probed the content of the Latent Heat lesson. Both groups progressed, the computer group significantly more than the control group. One can hypothesize that MBL facilitated learning in several ways. The students could see the temperature/time graph as they were performing the experiment, thereby making a more direct link between temperature and physical states. The large number of arrows (heat dollops) under the temperature plateau (during melting) may have impressed upon them that temperature does stay constant until the ice has melted. Finally the recording process was much easier for the computer group, and let them pay more attention to the phenomena themselves.

The patterns of wrong answers reveal that students accept more easily that temperature stays constant when heat is added to the ice/water mixture than when ice is added to it. This is because they think of cold as an entity, opposite of heat, instead of as absence of heat; in other words, ice is adding coldness, not removing heat from the liquid.

Thus cooling and heating are seen as different, rather than reverse processes, which could have different properties. Likewise, for the students, melting and freezing are different processes. It is relatively easy for them to accept that temperature stays constant during melting because "the heat is used to melt the ice." Not so when ice is added to the ice/water mixture: nothing (visibly) happens in terms of phase change, so the coldness provided by the extra ice has to make the mixture colder. The remedy to this situation is obviously to convince them that cold is absence of heat, and, as for specific heat, to teach the law of heat exchange.

The computer students also performed better (although not significantly) on Question 12, which presented the same problem in a novel context. The modal answer in the pretest was that, if heat was added to an ice/water mixture, its temperature would rise above 0°C; this is consistent with the conception that heat is hot: adding heat must raise the temperature, no matter what the circumstances. In the posttest the modal answer was the correct one.

HEAT AND TEMPERATURE (Questions 8 and 4)

Effect of heat on molecules. The modal answer was the correct one in both groups, both in the pretest and in the posttest. The control group however regressed significantly, with some students moving from the correct answer to "The molecules increase in size." A possible reason for this regression is that, having learned about thermal dilation, the students generalized from the macroscopic to the microscopic, concluding that molecules must increase in size when they get hotter. Both groups were given the kinetic molecular model but the computer group saw the molecules move on the screen while the control group only saw the model drawn on the blackboard. It seems that the dynamic computer model helped the students significantly in understanding that dilation is due not to the molecules increasing in size but in their average mutual distance increasing.

Difference between heat and temperature. Both groups progressed, the control group significantly more so than the computer group. The latter result is surprising because, on any other question for which a significant difference existed between the groups, the computer group progressed more than the control group. Two explanations suggest themselves. The control group may have acquired a clearer but superficial understanding that "heat and temperature are different things," a principle that was repeated several times during each class discussion. Such learning would be unrelated to that of the content of the demonstrations presented in class, i.e. would not be derived from understanding specific heat or latent heat. On the other hand, the control group may have reached a better conceptual understanding of heat and temperature while the computer group achieved better problem-solving. A preliminary analysis of the conceptual tests supports the second interpretation.

CALORIES

Students in both groups were taught the definition of a calorie (the quantity of heat necessary to raise the temperature of 1g of water by 1°C), and of latent heat (the quantity of heat necessary to melt 1g of substance), and were given homework problems manipulating number of calories, temperature and mass. Calories were not mentioned however in the lab activities themselves nor in the homework related to those activities. Student performed relatively poorly on the calorie questions and made hardly any progress. This is not surprising, since calorie computation was treated as a side issue in the teaching intervention. There is little reason to expect that a conceptual understanding that temperature stays constant during melting would help students with the arithmetic involved in computing latent heat of fusion problems.

RESULTS: CONCEPTUAL TESTS

The modal answers to each question in the pre- and post-interviews are presented in Table 18. A detailed analysis of the results is in progress. It is already clear that the control group shows significantly more progress than the computer group. This is reflected in the following overall statistical analysis. For the purpose of this analysis each possible answer was categorized as correct or incorrect (i.e., Is it something a physicist would say or not?). Each student was assigned a score calculated as [% correct choices-%incorrect choices] separately for the pre- and the post-interview. T-tests show that the computer group made no progress from pre- to post-interview (t(22)=-.27) whereas the control group progressed significantly (t(22)=4.58).

These results are consistent with those of the 1985 classroom Study, in which the control group showed some superiority in the verbal interviews. However the difference between the two groups is much more dramatic here. This may be due to the mode of testing-- multiple-choice written interviews versus verbal individual ones. It may also be that the greater difference in performance between the control and the computer group is related to the greater difference between the teaching interventions they received. The detailed analysis of the conceptual test results will enable us to characterize the differences between the two groups and test the above, and other, explanations.

CONCLUSIONS

The two classroom studies provide consistent information: The computer teaching succeeds in training students to solve quantitative problems about mass, heat and temperature. Computer students are better able than their control counterparts to manipulate units of heat, the computer advantage being particularly salient on the more difficult problems. This can be attributed to their using dollops (i.e., discrete units of heat) and seeing them on the screen as individual arrows. In contrast, traditionally taught students apply heat to substances in continuous fashion, and thus do not have direct phenomenological access to the concept of unit of heat, nor to the relation between number of heat units, mass and temperature changes.

MBL teaching also seems to be beneficial in the case of phase change: For both technical (better data, easier data collecting) and conceptual (very large number of arrows on the screen, under the temperature plateau, giving strong evidence that a large quantity of heat is being absorbed without causing a temperature rise) reasons, the computer students were better than control ones at mastering the concept of fixed point.

The Computer Laboratory Simulations are a promising teaching tool, particularly in conjunction with MBL. They offer a flexible alternative to hands-on experimentation, allowing students to "experiment" with a much larger variety of substances, to collect "perfect" and thus more convincing data, and to conduct a large number of experiments in a minimum amount of time. The computer group advantage on the specific heat questions is probably due not to the Computer Laboratory Simulations themselves, but to the fact that, through the Computer Laboratory Simulations, the computer students were presented more information about specific heat, showing them the different aspects of specific heat phenomena, and their interrelations.

Although they were better at solving problems involving number of units of heat, mass and temperature, the computer students did not show the same superiority when structurally identical problems were presented in a superficially novel context, e.g. when units of heat were replaced by amounts of time on a hot plate. (Such a context was less novel for the control students, who plugged the heaters in and out of wall sockets, and thus were used to quantifying heat by the amount of time the heater was left on.) From this, as well as the difficulties the control students had with the "unit of heat" problems, it is clear that students do not generally conceive of sources of heat as delivering units of heat. Even after the teaching intervention, many are still thinking of sources of heat as applying heat (of a certain degree). This issue will be addressed directly in future teaching interventions.

The results of both the tests and the interviews underline the prevalence of misconceptions, their resistance to change and their distorting effects on knowledge acquisition. Of the students who did not differentiate between heat and temperature before the teaching intervention, few did afterwards, at least in the expert sense of differentiation. Many had learned that there is a difference between heat and temperature, and most of those, that volume (or mass) has to be taken into account when measuring heat. But hardly any were willing to give up the notion that temperature measures heat. The result was either total confusion (a bigger volume of hot water is hotter than a smaller volume of the same hot water) or a concept of heat with two measures: degree and amount. The reader is referred to the Results of the1985 Study for a discussion of the difference between such a concept and the expert concept of heat. One consequence of this "mis-assimilated extensivity" is that its usefulness in applied situations is very limited (as in the Steel problem). In order to acquire the expert concept *amount of heat* , novices must do much more than learn that heat is extensive. They have to revise their concept of heat entirely, and especially give up the core notion of heat as hotness. Our teaching interventions did not accomplish that goal. On the basis of the interviews, one can postulate that, for the computer students, "unit of heat" meant "unit of heat of a certain degree."

Other examples of mis-assimilations are the fundamental misunderstanding about specific heat found in the 1985 Study and the notion that heat makes individual molecules expand.

Even after the teaching intervention, the students think of heat as an agent, whose fundamental nature remains unknown. (When asked "What is heat?," most of them say that they have no idea, or that it is like a ray or a wave.) They understand only some of its properties and some of its effects. For example, an intrinsic property of heat is that it is hot and thus makes the objects to which it is applied hotter. Heat also has the property of making molecules move faster. But whereas a physicist knows that heat is a form of energy (or, rather, of transferred energy), the students think of heat as an entity with the power of pushing molecules around, without understanding the origin of this power. In other words, for almost all students, heat remains an opaque concept, with several fundamental and unrelated properties. The students who try to relate the two properties of heat (hotness and pushing molecules) end up with the following schema: A source of heat makes molecules in the recipient move faster, this causes them to rub against each other, and the friction generates the heat that makes the recipient hotter. This schema also supports extensivity: A bigger mass contains more molecules, more molecules create more friction and thus generate more heat.

This last example, besides demonstrating the influence of pre-existing conceptions on the assimilation of knowledge, also shows the potential role of molecular models as unifying frameworks. We believe that providing students with the correct molecular model would greatly improve our teaching interventions. It would be very helpful in dispelling the notion of heat-as-hotness, in conveying the expert sense of the extensivity of heat and in demonstrating visually the relation among heat, mass and temperature. By examplifying the mechanism of heat flow, it would show that "making molecules move faster" and "making a substance hotter" are one and the same thing. It would demonstrate that heat flow is a function not only of the temperature of the "source" but also of the "recipient." It is also the only basis for understanding the relation between the different specific heat phenomena the students are exposed to; without it, specific heat remains a very mysterious property (too often identified with density). And it would help the students who think that specific heat as a kind of heat to view it instead as a property of substances.

We have several reasons to believe that molecular models help students. The interviews showed that all the students who displayed a complete understanding of thermal equilibrium in response to the question: "Why did the alcohol level stop?", explained thermal dilation in molecular terms. Similarly, all but two students who showed differentiation between heat and temperature in the post-interview used a molecular model to explain the difference. For example, they would say that temperature is the kinetic energy of one molecule while heat is the total energy of all the molecules. Although those definitions are not correct from the physicist's point of view, they capture one of the core distinctions between heat and temperature. Finally, class discussions revealed that specific heat could be easy to understand in the light of a molecular model. A few students understood the phenomenology of specific heat well enough to ask: "But then, why is it that different substances have different specific heats?" They were told that metal atoms have different weights, so that, for example, a 100g block of aluminum contains many more atoms than a 100g block of iron. So that, when the iron and the aluminum blocks receive the same amount of heat, that heat is shared among more atoms in the aluminum block. Each aluminum atom ends up with less additional energy and thus the temperature rise of the aluminum block is less than that of the iron block. It was clear that this explanation (which, admittedly is only one aspect of specific heat) made sense to the students, and that they enjoyed understanding the mechanical, molecular basis of an otherwise opaque phenomenon. We believe that the same would be true for other aspects of heat and temperature.

Microcomputers are ideally suited for presenting kinetic molecular models in which students can play an interactive role. Using the models in conjunction with MBL and Computer Laboratory Simulations would allow to capitalize on the advantages of the latter forms of computer teaching while remedying what appears now to be their major flaw: MBL and Computer Laboratory Simulations by themselves do not drive conceptual reorganization; they do not make students think differently about heat and temperature. In contrast, molecular models would provide an alternative conceptualization (a mechanical one), in the light of which the phenomena presented through MBL and Computer Laboratory Simulations would take on more meaning.

Lastly we have to address a puzzling question: Not only did our computer based interventions not help with conceptual reorganization, they appear to have been somewhat less effective than the control interventions, at the conceptual level. The detailed analysis of the 1986 interviews may shed some light on this finding, by revealing patterns of errors and systematic differences between the two groups. At this time we can only speculate that the novelty of the computer lessons may have been distracting: the students may have tended to view the lab activities as games, or focused too much on the technical aspects of those activities, to the detriment of the lesson content. Or the fact that they were presented information in novel form, and more information than the control group (see the Specific Heat Lesson) may have been overloading their capacity for assimilation.

DEVELOPING COMPUTER MOLECULAR MODELS

Our group is now in the process of developing several computer models of the kinetic behavior of molecules underlying thermal phenomena. Our main goals are to teach students that: (1) heat is the kinetic energy transferred from a hotter body to a colder one and (2) heat is extensive-it is measured by its amount, not its temperature.

Three models serve the first goal. Model 1 simply shows that, if the temperature of a substance increases, the average velocity of its molecules increases. Model 2 teaches the laws of two-particles collisions. Two particles with different masses collide repeatedly, exchanging momentum and energy. The velocities and amount of energy being exchanged are continuously displayed. In the long run, equilibration takes place. Thus Model 2 provides the students with the basic mechanism of heat exchange. Model 3 embodies it on a larger scale. It pictures a container, made out of big molecules, and a substance in the container (labelled a liquid), made out of smaller molecules. At the beginning, container and liquid are in thermal equilibrium: the molecules move and collide without overall energy changes. The container then becomes, and stays, hot (the velocity of its molecules increases). In stages, the container transfers energy to the liquid: the velocities of more and more liquid molecules increase, until equilibrium is reached. A variant of this model illustrates the "dolloping" process used in MBL. A heater made out of big molecules is placed inside the container. It is turned on and then off (the velocity of its molecules increases and then decreases), and energy spreads inside the container, increasing the velocities of the liquid molecules. By varying the quantity of liquid inside the container, one can easily show why the temperature rise caused by one dollop of heat is inversely proportional to the mass of liquid: the energy provided by the hot dolloper is distributed among different numbers of molecules.

The three models are meant to demonstrate why/how hotter bodies give heat to colder ones. On the average, the molecules in a hotter body have more kinetic energy than the molecules in a colder body. When the two bodies are brought in contact, their molecules collide, and energy is exchanged (Model 2). The hotter body molecules lose energy, which is gained by the colder body molecules. These models provide students with a mechanical account of heat exchange, which should help them understand that a substance getting hotter is one and the same thing as its molecules getting faster: those are not two separate effects of heat. It should also give them the sense that the same process underlies modes of heating that may at first look different (such as using a hot plate versus a dolloper.) This in turn may help them generalize what they learn with MBL, using the dolloper, to other contexts.

Models 2 and 3 will include and "energy counter", which will record the number of energy units being exchanged by the two particles (Model 2) or by the container and the liquid (Model 3). After being familiarized with Models 1, 2 and 3, the students will be presented Model 4, in which the units of heat (energy) are represented by dots. A grid is superimposed on the container. Each cell in the grid contains a random number of dots, which varies in time and from cell to cell; in other words, the molecules in each cell have a certain energy level, and exchange energy with the molecules in other cells. The students can "zoom in" on any cell to display the moving molecules inside the cell (all the cells contain the same number of molecules), and verify that the velocity of the molecules is proportional to the number of energy dots in the cell. Heat input is represented by increasing the number of dots in some cells, with subsequent redistribution of the dots among all cells. Model 4 will then be used to illustrate the relations between heat, mass and temperature. Model 4, we hope, will help students understand the extensivity of heat (amount of heat=number of dots) and thereby dissociate heat from temperature.

We are presently refining the four models and adapting them to the different lessons we intend to include in the Heat and Temperature curriculum. We also have started to explore the issue of how to model specific heat.

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Table 1a

Analysis of the answers to Question 5 of the multiple-choice test. 1985 Study.

Question 5. You put the same amount of heat into equal masses of rubber and gold. The temperature of the rubber increases by 10°C. The temperature of the gold increases by 100°C. Which of following is true?

A) Gold has a higher specific heat than rubber.

B) Rubber has a higher specific heat than gold.

C) Gold and rubber have the same specific heat.

D) One cannot tell from the information given whether gold or rubber has a higher specific heat.

Correct answer: B.

A. Nuber of students choosing each answer.

		Post				
		A	B	C	D	
Pre	A	30	9	1	3	43
	B	2	-	-	-	2
	C	-	-	-	-	0
	D	12	4	0	1	17
		44	13	1	4	

Computer group

		Post				
		A	B	C	D	
Pre	A	33	6	-	2	41
	B	3	-	-	-	3
	C	-	-	-	-	0
	D	9	-	-	5	14
		45	6	0	7	

Control group

B. % Students correct (chance level: 25%)

Computer		Control	
Pretest	Posttest	Pretest	Posttest
3%*b	21%	5%b	10%*b

C. Did the students improve?

		Post	
		Correct	Incorrect
Pre	Correct	0	2
	Incorrect	13	47

Computer

		Post	
		Correct	Incorrect
Pre	Correct	0	3
	Incorrect	6	50

Control

	Computer	Control
McNemar:	z=2.84*	z=1

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved	18%	5%	*

Table 1b

Analysis of the answers to Question 6 of the multiple-choice test. 1985 Study.

Question 6. After heating the pieces of rubber and gold as described in Question 5 you drop them in identical containers of cold water. The piece of rubber is in Beaker 1 and the piece of gold is in Beaker 2. Which of the following is true?

a)The final temperature in Beaker 1 will be higher than the final temperature in Beaker 2.
b)The final temperature in Beaker 2 will be higher than the final temperature in Beaker 1.
c)The final temperature in Beaker 1 and in Beaker 2 will be the same.

Correct answer: B.

A. Nuber of students choosing each answer.
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		Post			
		A	B	C	
Pre	A	-	-	3	3
	B	1	23	5	29
	C	6	15	9	30
		7	38	17	

Computer group

		Post			
		A	B	C	
Pre	A	-	3	1	4
	B	1	29	3	33
	C	-	18	4	22
		1	50	8	

Control group

B. % Students correct (chance level: 33%)

Computer		Control	
Pretest	Posttest	Pretest	Posttest
48%*a	27%	37%	14%*b

C. Did the students regress significantly?

		Post	
		Correct	Incorrect
Pre	Correct	9	21
	Incorrect	8	24

Computer

	Post	
	Correct	Incorrect
Pre	4	16
	4	33

Control

McNemar: z=-2.27*(regressed) z=-2.68*(regressed)

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved	-19%	-20%	NS

Table 2

Question 1: "Why does the level rise?"

Type of explanation (see text for detail):
Level 1 (L_1): Vague or irrelevant.
Level 2 (L_2): Force.
Level 3 (L_3): Molecules move faster.
Level 4 (L_4): Molecules move faster, they take more space and that make the level rise.
Level 5 (L_5): As L_4 plus adding heat is adding energy to the alcohol molecules.
Level 6 (L_6): The hot water molecules move faster than the alcohol molecules, when they hit each other the water molecules make the alcohol molecules move faster.
*=computer group

NOTE: Students who gave explanations at different levels were classified according to the highest of those levels.

		PRE					
POST		L_1	L_2	L_3	L_4	L_5	L_6
L_1	Computer	-	-	-	-	-	-
	Control	-	-	-	-	-	-
L_2	Computer	-	1*	1*	-	-	-
	Control	-	1	-	-	-	-
L_3	Computer	-	2*	1*	-	-	-
	Control	-	-	2	-	-	-
L_4	Computer	-	1*	1*	7*	-	-
	Control	1	-	2	4	-	-
L_5	Computer	-	1*	2*	1*	-	-
	Control	-	1	2	2	-	-
L_6	Computer	-	-	-	-	-	-
	Control	-	-	-	1	-	-

Table 3

Question 2: "Will the level stop?"

			PRE TEST	
			YES	NO
POST TEST	YES	Computer	4*	9*
		Control	8	5
	NO	Computer	1*	4*
		Control	2	2

* = Computer group
No * = Control group

Table 4

Question 3: "Why does the level stop?"

			PRE				
			EVIDENCE FOR EQUILIBRIUM			NEUTRAL	EVIDENCE AGAINST EQUILIB.
			Equalization	Transfer	Eq.+Tr.		
POST	EVIDENCE FOR EQUIL.	Equal.	2*	1*	-	1*	-
			2	-	-	1	-
		Transf.	-	-	-	-	-
			-	-	-	1	-
		Eq.+Tr.	1*	-	-	1*	1*
			2	-	-	2	-
	NEUTRAL		-	-	-	2*	1*
			2	-	-	2	1
	EVIDENCE AGAINST EQUIL.		-	-	-	1*	2*
			-	-	-	-	2
	NOT ASKED		-	-	-	3*	2*
			-	-	-	1	1

*=Computer Group
No * = Control group

Table 5

Question 3: "Why does the level stop?"

		PRE TEST	
		Evidence for Equilibrium	No Evidence for Equilibrium
Evidence for Equilibrium	Comp.	4*	3*
	Contr.	4	4
No Evidence for Equilibrium	Comp.	0*	6*
	Contr.	2	5

*=computer group
No *=control group

Table 6

Question 4: "Will more water make the level rise higher?"

			PRE				
			NO		YES	KEEPS GOING	TOTAL
			Explan.	No Explan.			
POST	NO	Explanation	5*	-	2*	1*	8*
			6	1	1	1	9
		No Explan.	-	1*	-	-	1*
			-	-	-	1	1
	YES		2*	-	1*	-	3*
			1	-	1	1	3
	KEEPS GOING		-	-	-	-	0
			-	-	1	-	1
	TOTAL ASKED		7*	1*	3*	1*	12*
			7	1	3	3	14
	NOT ASKED		1*	2*	1*	2*	6*
			1	1	-	1	3
	TOTAL		8*	3*	4*	3*	18*
			8	2	3	4	17

*=Computer Group
No * = Control Group

Table 7

Questions 4 and 5 : Evidence for equilibrium.

	PRE			
POST	Equilibrium	Neutral	No Equilibrium	Total Asked
Equilibrium	3*	-	5*	1*
	5	1	2	1
Neutral	-	-	-	-
	-	-	1	1
No Equilibrium	2*	-	2*	1
	1	-	4	1
Total Asked	1*	-	7*	-
	1	1	7	-
Not Asked	1*	1*	4*	-
	1	-	2	-

*=Computer group
No *=Control group

Table 8

Questions 2,3,4 and 5: Evidence for Equilibrium.

			PRE TEST		
			Yes	No	Total
POST TEST	Yes	Comp.	1*	6*	7*
		Contr.	6	3	9
	No	Comp.	2*	9*	11*
		Contr.	1	7	8
	Total	Comp.	3*	15*	
		Contr.	7	10	

* = Computer group
No * = Control group

Table 9

Question 6: Alcohol and Water - Equilibrium.

		PRE TEST		
		No Equilibrium	Equilibrium	Total
No Equilibrium	Comp	6*	3*	9*
	Contr.	4	2	6
POST TEST				
Equilibrium	Comp.	6*	1*	7*
	Contr.	4	6	10
Total	Comp.	12*	4*	
	Contr.	8	8	

*= Computer group
No *= Control group

Table 10

Questions 2-6: Equilibrium

		PRE TEST				
		NN	NY	YN	YY	TOTAL
POST TEST	NN	4* 2	1* 1	- -	- 1	5* 4
	NY	3* 2	- -	- -	- 1	3* 3
	YN	2* 1	- -	2* 1	- -	4* 2
	YY	2* 2	1* 1	1* 1	1* 3	5* 7
	TOTAL	11* 6	2* 2	3* 2	1* 5	17* 15

*=Computer group
No *=Control group

NN= No equilibrium on Questions 2-5, and no equilibrium on Question 6.

NY= No equilibrium on Questions 2-5, and equilibrium on Question 6.

YN= Equilibrium on Questions 2-5, and no equilibrium on Question 6.

YY= Equilibrium on Questions 2-5, and equilibrium on Question 6.

TABLE 11 The beaker question

		PRE TEST					
		Heat Intensive	Non-differentiation	Confused/ Challenge	More heat (no explanation)	Temperature and Amount	Differentiation
POST TEST	Heat Intensive	4*	-	-	-	-	-
		2	-	-	-	-	-
	Non-Differentiation	2*	2*	-	1*	-	-
		2	-	-	-	-	-
	Confused/ Challenged	-	-	1*	1*	-	-
		1	-	1	-	-	-
	More heat (no explanation)	3*	-	-	-	-	-
		1	-	-	1	-	-
	Temperature and Amount	1*	-	-	-	-	-
		1	-	-	-	-	-
	Differentiation	-	-	-	-	-	1*
		5	1	-	-	1	2

* = Computer
no * = Control

Progress from Pre- to Post- Test

	Progress	No Progress	Regression
Computer	6	8	2
Control	13	5	0

Table 12

Steel Question - Concept of heat.

POST TEST	PRE TEST				
	Heat Intensive	Non-Differentiated	Incomplete Differentiation	Differentiated	Total Correct
Heat Intensive	4*	-	1*	-	5*
	-	-	-	-	-
Non-Differentiated	4*	3*	-	-	7*
	4	-	-	-	4
Incomplete Differentiation	2*	-	-	-	2*
	4	-	2	-	6
Differentiation	-	1*	-	-	1*
	2	-	1	3	6
Total Correct	10*	4*	1*	-	15*
	10	-	3	3	16*

*=Computer Group

Table 13

Correlation between the "steel" and "beaker" questions.
Pre-Tests only.

			STEEL QUESTION			
			Heat Intensive	Non-Differentiation	Incomplete Differentiation	Differentiation
BEAKER QUESTION		Heat Intensive	9^*	1^*	-	-
			8	-	3	-
		Non-Differentiation	-	1^*	-	-
			1	-	-	-
	INCOMPLETE DIFFERENTIATION	Confused	1^*	-	1^*	-
			-	-	-	-
		More Heat (No Explanation)	-	2^*	-	-
			1	-	-	-
		Temperature and Amount	-	-	-	-
			-	-	-	1
		Differentiation	-	-	-	-
			-	-	-	2

*=Computer Group

Correlation between answers to the "beaker" and the "steel" questions.

	Steel category higher than Beaker category	Steel category same as Beaker category	Steel category lower than Beaker category
Computer Group	2^*	11^*	3^*
Control Group	4	10	2
Total Number	6	21	5

$X^2=15$, df=2, significant.

Table 14

Correlation between the "steel" and "beaker" questions.
Post-tests only.

			STEEL QUESTION			
			Heat Intensive	Non-Differentiation	Incomplete Differentiation	Differentiation
BEAKER QUESTION		Heat Intensive	3*	1*	-	-
			1	1	-	-
		Non-Differentiation	-	4*	-	-
			-	2	1	-
	INCOMPLETE DIFFERENTIATION	Confused	1*	2*	-	-
			-	-	-	-
		More Heat (No Explanation)	-	-	3*	-
			-	-	1	-
		Temperature and Amount	-	-	-	-
			-	1	1	-
		Differentiation	-	-	-	1*
			-	1	2	5

*=Computer Group

Correlation between answers to the "beaker" and the "steel" questions.

	Steel category higher than Beaker category	Steel category same as Beaker category	Steel category lower than Beaker category
Computer Group	1*	11*	3*
Control Group	2	9	4
Total Number	3	20	7

χ^2=15.8, df=2, significant.

Table 15a

STUDY 2: Correlation between verbal and written interview.
Students 1-11.

	STUDENT											
	1	2	3	4	5	6	7	8	9	10	11	$\bar{x}$
1	0%	100	100	-	100	100	100	100	100	100	-	73
2	-*	-	-	-	-	-	-	-	-	-	-	-
3	88	63	88	88	75	63	75	88	88	75	50	77
4	83	67	50	-	50	50	-	50	-	50	50	41
5	-	40	40	60	60	40	-	60	40	60	40	44
6a	-	-	-	50	-	-	-	-	-	-	-	-
6b	57	86	71	-	29	57	57	71	57	86	57	63
7	-	-	67	-	67	-	-	-	-	50	67	63
8	58	58	75	50	75	42	67	75	83	42	83	64
9	100	57	57	100	71	43	43	86	43	57	43	64
10	100	100	100	100	100	100	100	75	75	75	100	93
11a	-	80	-	100	100	80	60	60	80	60	80	78
11b	-	57	-	71	71	86	71	57	71	100	100	76
12	-	100	-	100	60	80	60	80	80	60	100	80
13	-	25	50	50	-	50	25	100	50	50	50	50
14a	-	50	-	50	-	-	100	50	75	-	50	63
14b	-	86	100	71	-	86	100	71	71	100	71	84
15	-	67	67	89	-	67	78	78	100	89	78	79
16	-	46	82	73	-	100	73	73	82	82	100	79

(*) the bar indicates that the student skipped the question.

Students 1-11 were interviewed before taking the written test.

(continued over)

Table 15b

STUDY 2: Correlation between verbal and written interview.
Students 12-22.

	STUDENT											
	12	13	14	15	16	17	18	19	20	21	22	$\bar{x}$
1	100%	100	100	100	100	100	100	100	-	100	100	91
2	100	-*	-	67	-	-	-	-	-	-	-	84
3	-	75	88	-	88	75	88	75	88	88	100	85
4	-	75	83	-	75	-	67	50	-	-	-	44
5	0	60	80	40	100	40	60	-	-	-	60	49
6a	-	-	-	-	-	-	-	-	-	-	-	-
6b	57	43	86	86	71	71	57	71	86	71	57	69
7	-	33	-	-	100	100	-	-	-	83	100	83
8	57	58	83	58	75	75	83	75	67	50	83	70
9	71	86	57	86	100	86	86	71	57	71	86	78
10	75	75	75	75	75	100	75	75	100	100	75	82
11a	80	80	80	60	60	100	100	100	20	100	80	78
11b	86	86	57	100	57	71	71	71	71	71	71	74
12	80	40	80	-	80	100	60	60	100	40	60	70
13	50	-	-	-	100	75	50	50	100	75	100	65
14a	100	50	50	-	75	50	100	-	50	100	-	72
14b	71	43	57	-	86	71	57	-	100	71	71	70
15	67	33	89	-	78	89	56	-	78	78	78	72
16	55	82	82	-	100	82	64	-	82	73	64	67

(*) the bar indicates that the student skipped the question.

Students 12-22 were interviewed after taking the written test.

Table 16

Results from the multiple-choice test

Classroom study - Spring 1986

NOTE for test B (% students correct)
a* = Significant above chance at the .05 level
b* = Significant below chance at the .05 level

Question 1: A quantity of heat is put into 100g of water and causes that water's temperature to rise 20° C. If the same quantity of heat is put into 200g of water what temperature rise will it cause?

A) 40° C B) 20° C C) 30° C D) 10° C

Correct Answer: D

A. Number of students choosing each answer:

Computer Group

		POST				
		A	B	C	D	
PRE	A	0	0	0	1	1
	B	0	0	0	12	12
	C	0	0	0	0	0
	D	0	0	0	10	10
		0	0	0	23	

Control Group

		POST				
		A	B	C	D	
PRE	A	1	0	0	5	6
	B	0	0	0	3	3
	C	0	0	0	0	0
	D	0	0	0	14	14
		1	0	0	22	

B. % of students correct (chance level: 25%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
43% a*	100% a*	61% a*	96% a*

C. Did students improve significantly?

Computer Group

		POST	
		Correct	Incorrect
PRE	Correct	10	0
	Incorrect	13	0

Control Group

		POST	
		Correct	Incorrect
PRE	Correct	14	0
	Incorrect	8	1

Mc Nemar: X^2=11.08*
(*=significant progress)

Binomial: p=.004*

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	57	35	n.s.

Table 16-1

Question 2: You start with the same quantity of water and alcohol both at room temperature. You heat them on identical hot plates for the same amount of time. The temperature of the water reaches 60° C. What temperature will the alcohol reach?

A) 60°C B) more than 60°C C) less than 60°C

Correct Answer: B

A. Number of students choosing each answer:

Computer Group

		POST A	POST B	POST C	
PRE	A	0	3	0	3
	B	0	9	1	10
	C	0	9	1	10
		0	21	2	

Control Group

		POST A	POST B	POST C	
PRE	A	0	4	0	4
	B	0	10	0	10
	C	0	9	0	9
		0	23	0	

B. % of students correct (chance level: 33.3%)

Computer Group Pre Test	Computer Group Post Test	Control Group Pre Test	Control Group Post Test
43% n.s.	91% a*	43% n.s.	100% a*

C. Did students improve significantly?

Computer Group

		POST Correct	POST Incorrect
PRE	Correct	9	1
	Incorrect	12	1

Mc Nemar: $X^2=7.69*$

(*=significant progress)

Control Group

		POST Correct	POST Incorrect
PRE	Correct	10	0
	Incorrect	13	0

Mc Nemar: $X^2=11.08*$

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	48	57	n.s.

Table 16-2

Question 3: Two units of heat are put into 100g of water at 25°C (Beaker 1) and four units of heat are put into 200g of water at 50°C (Beaker 2). Which of the following is true?

A) The temperature change in beaker 1 is less than the temperature change in beaker 2.
B) The temperature change in beaker 1 is more than the temperature change in beaker 2.
C) The temperature change in beaker 1 is the same as the temperature change in beaker 2.
D) The final temperature is the same in beaker 1 and in beaker 2.
E) None of the above.

Correct Answer: C

A. Number of students choosing each answer:

Computer Group
POST

		A	B	C	D	E	
	A	0	0	5	2	0	7
	B	0	0	0	0	0	0
PRE	C	2	0	4	0	0	6
	D	0	0	7	2	0	9
	E	0	0	0	0	1	1
		2	0	16	4	1	

Control Group
POST

		A	B	C	D	E	
	A	3	0	1	1	0	5
	B	0	0	0	0	0	0
PRE	C	2	0	3	1	0	6
	D	2	0	3	5	0	10
	E	1	0	0	1	0	2
		8	0	7	8	0	

B. % of students correct (chance level: 20%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
26% n.s.	70% a*	26% n.s.	30% n.s.

C. Did students improve significantly?

Computer Group
POST

		Correct	Incorrect
PRE	Correct	4	2
	Incorrect	12	5

Control Group
POST

		Correct	Incorrect
PRE	Correct	3	3
	Incorrect	4	13

Mc Nemar: $X^2=5.79*$
(*= significant progress)

Binomial: p=.5 n.s.

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	43	4	* (computer better)

Table 16-3

Question 4: The measure of temperature is:

A) Read on a thermometer.
B) The same as the measure of heat.
C) The specific heat of a substance.
D) The total energy of the molecules of a substance.
E) Both A) and B).

Correct Answer: A

A. Number of students choosing each answer:

Computer Group
POST

		A	B	C	D	E	
	A	11	1	0	0	3	15
	B	0	0	0	0	0	0
PRE	C	1	0	0	0	0	1
	D	0	0	0	0	0	0
	E	6	0	0	0	1	7
		18	1	0	0	4	

Control Group
POST

		A	B	C	D	E	
	A	9	0	0	0	0	9
	B	0	0	0	0	0	0
PRE	C	1	0	0	0	0	1
	D	2	0	0	0	1	3
	E	9	0	0	0	1	10
		21	0	0	0	2	

B. % of students correct (chance level: 20%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
65% a*	78% a*	39% a*	91% a*

C. Did students improve significantly?

Computer Group
POST

		Correct	Incorrect
PRE	Correct	11	4
	Incorrect	7	1

Control Group
POST

		Correct	Incorrect
PRE	Correct	9	0
	Incorrect	12	2

Mc Nemar: X^2=.36 n.s.
(*= significant progress)

Mc Nemar: X^2=10.08*

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	13	52	* (computer worse)

Table 16-4

Question 5: You put the same amount of heat into equal masses of rubber and gold. The temperature of the rubber increases by 10°C. The temperature of the gold increases by 100°C. Which of the following is true?

A) Gold has a higher specific heat than rubber.
B) Rubber has a higher specific heat than gold.
C) Gold and rubber have the same specific heat.
D) One cannot tell from the information given whether gold or rubber has a higher specific heat.

Correct Answer: B

A. Number of students choosing each answer:

		Computer Group				
		POST				
		A	B	C	D	
PRE	A	1	12	0	1	14
	B	0	5	0	0	5
	C	0	0	0	0	0
	D	2	2	0	0	4
		3	19	0	1	

		Control Group				
		POST				
		A	B	C	D	
PRE	A	6	9	0	0	15
	B	2	2	0	0	4
	C	0	0	0	0	0
	D	0	4	0	0	4
		8	15	0	0	

B. % of students correct (chance level: 25%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
22% n.s.	83% a*	17% n.s.	65% a*

C. Did students improve significantly?

	Computer Group	
	POST	
	Correct	Incorrect
PRE Correct	5	0
PRE Incorrect	14	4

	Control Group	
	POST	
	Correct	Incorrect
PRE Correct	2	2
PRE Incorrect	13	6

Mc Nemar: $X^2=12.07*$
(*=significant progress)

Mc Nemar: $X^2=6.67*$

D. Did the computer group improve significantly more than the control group?

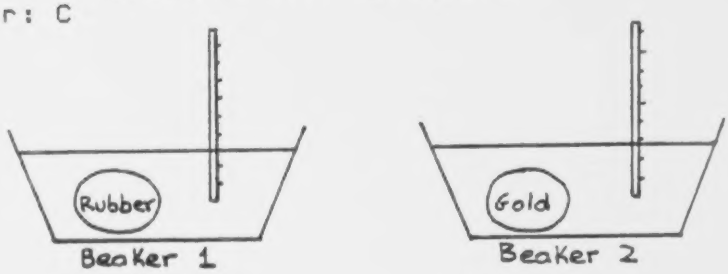
	Computer	Control	Difference
% Improved:	61	52	n.s.

Table 16-5

Question 6: After heating the pieces of rubber and gold as described in question 5 you drop them in identical containers of cold water. The piece of rubber is in beaker 1 and the piece of gold is in beaker 2. Which of the following id true?

A) The final temperature in beaker 1 will be higher than the final temperature in beaker 2.
B) The final temperature in beaker 2 will be higher than the final temperature in beaker 1.
C) The final temperatures in beaker 1 and in beaker 2 will be equal.

Correct Answer: C



A. Number of students choosing each answer:

Computer Group

		POST			
		A	B	C	
PRE	A	0	1	0	1
	B	7	8	5	20
	C	0	1	1	2
		7	10	6	

Control Group

		POST			
		A	B	C	
PRE	A	1	2	1	4
	B	6	10	0	16
	C	2	1	0	3
		9	13	1	

B. % of students correct (chance level : 33.3%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
9% b*	26% n.s.	13% b*	4% b*

C. Did students improve significantly?

Computer Group

		POST	
		Correct	Incorrect
PRE	Correct	1	1
	Incorrect	5	16

Binomial: p=.11 n.s.

Control Group

		POST	
		Correct	Incorrect
PRE	Correct	0	3
	Incorrect	1	19

Binomial: p= .31 n.s

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	17	-9	n.s.

Table 16-6

Question 7: The specific heat of steel is higher than the specific heat of silver. 200g of steel and 200g of silver are both heated to 60°C. They are placed in identical containers of cold water. Which of the following is true:

A) The silver makes the water hotter than the steel does.
B) The steel makes the water hotter than the silver does.
C) The water reaches the same temperature in the two containers.

Correct Answer: B

A. Number of students choosing each answer:

Computer Group

		POST A	POST B	POST C	
PRE	A	0	4	0	4
	B	2	14	1	17
	C	0	1	1	2
		2	19	2	

Control Group

		POST A	POST B	POST C	
PRE	A	0	3	0	3
	B	5	9	0	14
	C	1	3	1	5
		6	15	1	

B. % of students correct (chance level: 33.3%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
74% a*	83% a*	61% a*	70% a*

C. Did students improve significantly?

Computer Group

		POST Correct	POST Incorrect
PRE	Correct	14	3
	Incorrect	5	1

Binomial: p=.36 n.s.

Control Group

		POST Correct	POST Incorrect
PRE	Correct	9	5
	Incorrect	7	2

Mc Nemar: X^2=.08 n.s.

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	9	9	n.s.

Table 16-7

Question 8: When heat is added to substance, the molecules:

A) Increase in size.
B) Increase in energy.
C) Increase in mass.
D) Start dividing.

Correct Answer: B

A. Number of students choosing each answer:

Computer Group

		POST A	POST B	POST C	POST D	
PRE	A	2	0	0	0	2
	B	1	11	1	1	14
	C	0	0	0	0	0
	D	0	4	0	1	5
	N.A	1	1	0	0	2
		4	16	1	2	

Control Group

		POST A	POST B	POST C	POST D	
PRE	A	1	0	0	0	1
	B	5	14	1	1	21
	C	1	0	0	0	1
	D	0	0	0	0	0
	N.A	0	0	0	0	0
		7	14	1	1	

(N.A = no answer)

B. % of students correct (chance level: 25%)

Computer Group Pre Test	Computer Group Post Test	Control Group Pre Test	Control Group Post Test
61% a*	70% a*	91% a*	61% a*

C. Did students improve significantly?

Computer Group

	POST Correct	POST Incorrect
PRE Correct	11	3
PRE Incorrect	5	4

Binomial: p=.36 n.s.

Control Group

	POST Correct	POST Incorrect
PRE Correct	14	7
PRE Incorrect	0	2

Binomial: p=.008 *
(*= significant regress)

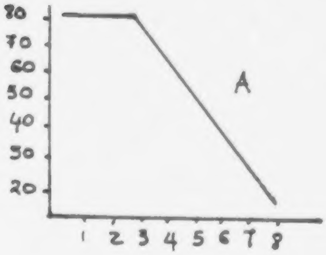
D. Did the computer group improve significantly more than the control group?

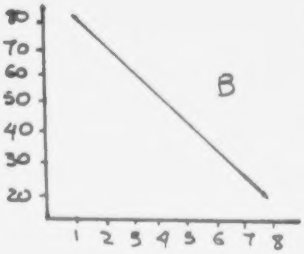
	Computer	Control	Difference
% Improved	9	-30	n.s.

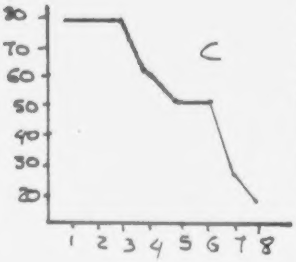
Table 16-8

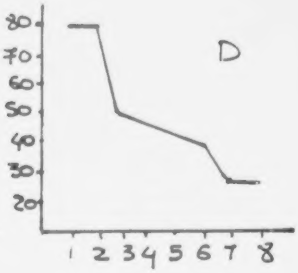
Question 9: Which graph below best represents the data in the following table:
A) B) C) D)

Time (minutes)	1	2	3	4	5	6	7	8
Temperature(C)	80°	80°	80°	60°	50°	50°	30°	20°









Correct Answer: C

A. Number of students choosing each answer:

Computer Group

		POST				
		A	B	C	D	
PRE	A	0	4	0	0	4
	B	0	0	0	0	0
	C	3	0	16	0	19
	D	0	0	0	0	0
		3	4	16	0	

Control Group

		POST				
		A	B	C	D	
PRE	A	0	1	0	0	1
	B	1	0	1	0	2
	C	1	0	18	0	19
	D	0	0	1	0	1
		2	1	20	0	

B. % of students correct (chance level: 25%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
83% a*	70% a*	83% a*	87% a*

C. Did students improve significantly?

Computer Group

		POST	
		Correct	Incorrect
PRE	Correct	16	3
	Incorrect	0	4

Binomial: p=.5 n.s.

Control Group

		POST	
		Correct	Incorrect
PRE	Correct	18	1
	Incorrect	1	2

Binomial: p=.75 n.s.

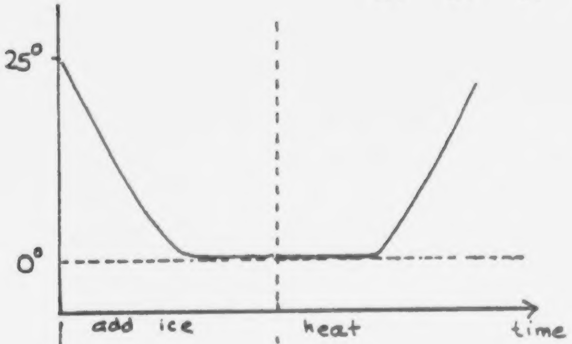
D. Did the computer group improve significantly more than the control group?

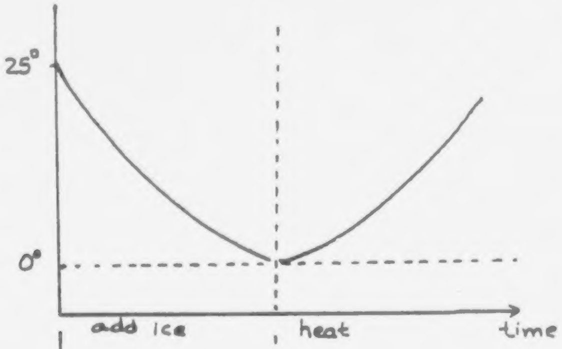
	Computer	Control	Difference
% Improved:	-13	4	n.s.

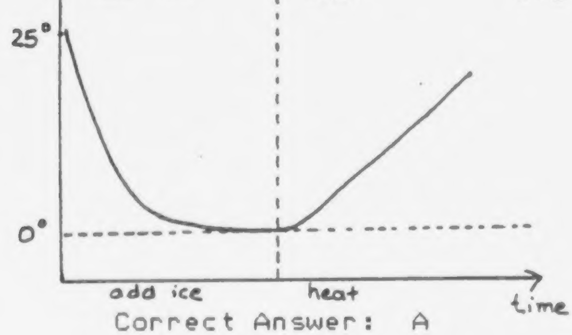
Table 16-9

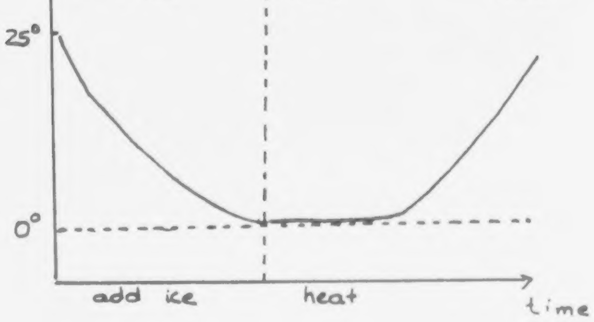
Question 10: You have a room temperature water (25°C). You add ice to it, let it melt, and keep adding ice until it stops melting. Then you put the beaker of ice/water mixture on a hot plate and heat it until the ice is all melted and the water warms up. Which of the following graphs represents the temperature in the beaker:

A) B) C) D)









Correct Answer: A

A. Number of students choosing each answer:

Computer Group

		POST A	B	C	D	
PRE	A	5	0	0	2	7
	B	6	1	0	2	9
	C	4	0	0	1	5
	D	2	0	0	0	2
		17	1	0	5	

Control Group

		POST A	B	C	D	
PRE	A	5	2	0	2	9
	B	4	0	0	3	7
	C	2	0	0	2	4
	D	1	0	0	2	3
		12	2	0	9	

B. % of students correct (chance level: 25%)

Computer Group Pre Test	Computer Group Post Test	Control Group Pre Test	Control Group Post Test
35% n.s.	75% a*	39% n.s.	52% a*

Table 16-10

C. Did students improve significantly?

	Computer Group POST			Control Group POST	
	Correct	Incorrect		Correct	Incorrect
PRE Correct	5	3	PRE Correct	5	4
PRE Incorrect	12	3	PRE Incorrect	7	7

Mc Nemar: X^2=4.27* Mc Nemar: X^2=.36 n.s.

(*=significant progress)

D. Did the computer group inprove significantly more than the control group?

	Computer	Control	Difference
% Improved:	39	13	* (computer better)

Table 16-11

Question 11: A lump of hot iron raises 100g of water from 30°C to 60°C. An identical lump of hot iron will raise 100g of water from 50°C to:

A) 80°C B) 100°C C) 60°C D) none of the above

Correct Answer: A

A. Number of students choosing each answer:

Computer Group

		POST A	POST B	POST C	POST D	
PRE	A	12	0	0	0	12
	B	3	3	1	0	7
	C	1	0	2	0	3
	D	0	1	0	0	1
		16	4	3	0	

Control Group

		POST A	POST B	POST C	POST D	
PRE	A	12	1	2	0	15
	B	4	3	0	0	7
	C	0	0	1	0	1
	D	0	0	0	0	0
		16	4	3	0	

B. % of students correct (chance level: 25%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
52% a*	70% a*	65% a*	70% a*

C. Did students improve significantly?

Computer Group

		POST Correct	POST Incorrect
PRE	Correct	12	0
	Incorrect	4	7

Binomial: p=.06 n.s.

Control Group

		POST Correct	POST Incorrect
PRE	Correct	12	3
	Incorrect	4	4

Binomial: p=.5 n.s.

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	17	4	n.s.

Table 16-12

Question 12: The thermometer is in a beaker of ice and water. It reads 0°C. We put the beaker on a hot plate for a minute. After that time there is still some ice left in the beaker. What does the thermometer read?

A) Less than 0°C B) 0°C C) More than 0°C

Correct Answer: B

A. Number of students choosing each answer:

Computer Group		POST A	POST B	POST C	
	A	0	2	0	2
PRE	B	0	4	2	6
	C	0	11	4	15
		0	17	6	

Control Group		POST A	POST B	POST C	
	A	0	0	0	0
PRE	B	0	6	2	8
	C	0	8	7	15
		0	14	9	

B. % of students correct (chance level: 33.3%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
26% n.s.	74% a*	35% n.s.	61% n.s.

C. Did students improve significantly?

Computer Group		POST Correct	POST Incorrect
PRE	Correct	4	2
	Incorrect	13	4

Control Group		POST Correct	POST Incorrect
PRE	Correct	6	2
	Incorrect	8	7

Mc Nemar: $X^2=6.67*$
(*=significant progress)

Mc Nemar: $X^2=2.5$ n.s.

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	48	26	n.s.

Table 16-13

Question 13: How many calories must be added to 50g of water to raise its temperature by°10 C?

A) 500 B) 10 C) 50 D) 5

Correct Answer: A

A. Number of students choosing each answer:

Computer Group

		POST				
		A	B	C	D	
PRE	A	1	5	0	0	6
	B	1	3	1	1	6
	C	2	3	2	1	8
	D	1	0	0	2	3
		5	11	3	4	

Control Group

		POST				
		A	B	C	D	
PRE	A	8	1	2	0	11
	B	0	2	0	2	4
	C	4	1	0	0	5
	D	1	0	1	1	3
		13	4	3	3	

B. % of students correct (chance level: 25%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
26% n.s.	22% n.s.	48% a*	57% a*

C. Did students improve significantly?

Computer Group

		POST	
		Correct	Incorrect
PRE	Correct	1	5
	Incorrect	4	13

Binomial: p=.75 n.s.

Control Group

		POST	
		Correct	Incorrect
PRE	Correct	8	3
	Incorrect	5	7

Binomial: p=.36 n.s.

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	-4	9	n.s.

Table 16-14

Question 14: It takes 600 calories to melt 200g of a substance. What is the latent heat of fusion of that substance?

A) .33 B) 120,000 C) 3 D) 600

Correct Answer: C

A. Number of students choosing each answer:

Computer Group

		POST A	POST B	POST C	POST D	
PRE	A	0	0	1	1	2
	B	0	1	1	0	2
	C	0	2	12	3	17
	D	0	1	0	1	2
	N.A	0	0	0	0	0
		0	4	14	4	

Control Group

		POST A	POST B	POST C	POST D	
PRE	A	0	1	2	0	3
	B	0	0	2	0	2
	C	1	3	8	2	14
	D	0	0	1	2	3
	N.A	0	0	0	1	1
		1	4	13	5	

(N.A= no answer)

% of students correct (chance level: 25%)

Computer Group Pre Test	Computer Group Post Test	Control Group Pre Test	Control Group PostTest
74% a*	61% a*	61% a*	57% a*

C. Did students improve significantly?

Computer Group

		POST Correct	POST Incorrect
PRE	Correct	12	5
	Incorrect	2	4

Control Group

		POST Correct	POST Incorrect
PRE	Correct	8	6
	Incorrect	5	4

Binomial: p=.23 n.s.

Mc Nemar: $X^2=0$ n.s.

D. Did the computer group improve significantly more then the control group?

	Computer	Control	Difference
% Improved:	-13	-4	n.s.

Table 16-15

Question 15: 1 unit of heat raises the temperature of a quantity of copper from 10°C to 15°C. 2 units of heat will raise the temperature of the same quantity of copper from 5°C to:

A) 10°C B) 30°C C) 20°C D) 15°C

Correct Answer: D

A. Number of students choosing each answer:

		Computer Group				
		POST				
		A	B	C	D	
	A	4	0	1	1	6
PRE	B	0	0	1	0	1
	C	1	0	0	2	1
	D	2	0	0	11	13
		7	0	2	14	

		Control Group				
		POST				
		A	B	C	D	
	A	5	1	1	4	11
PRE	B	0	0	0	0	0
	C	0	0	0	3	3
	D	0	0	0	9	9
		5	1	1	16	

B. % of students correct (chance level: 25%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
57% a*	61% a*	39% n.s.	70% a*

C. Did students improve significantly?

	Computer Group	
	POST	
	Correct	Incorrect
Correct	11	2
PRE		
Incorrect	3	7

Binomial: p=.5 n.s.

	Control Group	
	POST	
	Correct	Incorrect
Correct	9	0
PRE		
Incorrect	7	7

Binomial: p=.008 *
(*=significant progress)

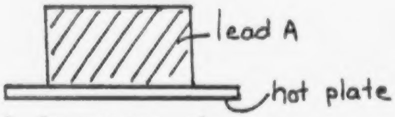
D. Did the computer group improve significantly more than the control group?

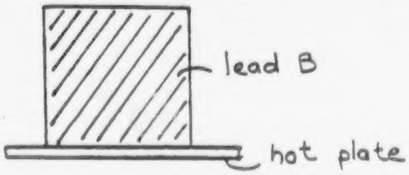
	Computer	Control	Difference
% Improved:	4	30	* (control better)

Table 16-16

Question 16: A block of lead A is placed on a hot plate and kept on it for 2 seconds. Another block of lead B, twice as big and at the same initial temperature as block A, is placed on an identical hot plate and kept on it for 4 seconds. Neither has time to reach the temperature of the hot plate. The final temperature of block B is:

A) The same as the final temperature of block A.
B) Higher than the final temperature of block A.
C) Lower than the final temperature of block A.





Correct Answer: A

A. Number of students choosing each answer:

		Computer Group POST			
		A	B	C	
PRE	A	11	2	3	16
	B	3	1	1	5
	C	1	0	1	1
		15	3	5	

		Control Group POST			
		A	B	C	
PRE	A	12	1	2	15
	B	2	0	1	3
	C	3	0	2	5
		17	1	5	

B. % of students correct (chance level: 33.3%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
70% a*	65% a*	65% a*	74% a*

C. Did students improve significantly?

	Computer Group POST	
	Correct	Incorrect
PRE Correct	11	5
PRE Incorrect	4	3

	Control Group POST	
	Correct	Incorrect
PRE Correct	12	3
PRE Incorrect	5	3

Binomial: p=.5 n.s.

Binomial: p=.3 n.s.

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	-4	9	n.s.

Table 16-17

Question 17: If 200 calories are necessary to raise the temperature of 1g of substance by $5^{\circ}C$, how many calories will it take to raise the temperature of 10g of the same substance by $2^{\circ}C$?

A) 2,000 B) 80 C) 1,000 D) 800

Correct Answer: D

A. Number of students choosing each answer:

Computer Group		POST A	POST B	POST C	POST D	
PRE	A	0	0	0	2	2
	B	0	0	2	3	5
	C	2	0	0	4	6
	D	2	0	3	5	10
		4	0	5	14	

Control Group		POST A	POST B	POST C	POST D	
PRE	A	2	0	0	1	3
	B	0	1	0	1	2
	C	1	3	1	2	7
	D	2	4	1	4	11
		5	8	2	8	

B. % of students correct (chance level: 25%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
43% a*	61% a*	48% a*	35% n.s.

C. Did students improve significantly?

Computer Group	POST Correct	POST Incorrect
PRE Correct	5	5
PRE Incorrect	9	4

Mc Nemar: $X^2=.64$ n.s.

Control Group	POST Correct	POST Incorrect
PRE Correct	4	7
PRE Incorrect	4	8

Mc Nemar: $X^2=.36$ n.s.

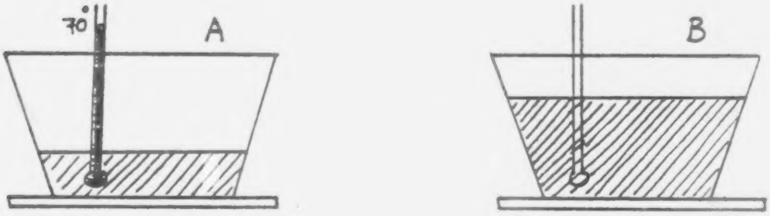
D. Did the computer group improve significantly more than the control group?

	Conputer	Control	Difference
% Improved:	17	-13	n.s.

Table 16-18

Question 18: One cup of oil is poured in a pot A and 2 cups of the same temperature oil are poured in pot B. The two pots are kept on identical hot plates for the same amount of time. The temperature in pot A reaches 70°C. What is the temperature reached in pot B?

A) 35°C B) 70°C C) 140°C D) 100°C



Correct Answer: A

A. Number of students choosing each answer:

Computer Group

		POST A	POST B	POST C	POST D	
	A	9	0	0	0	9
PRE	B	5	0	2	0	7
	C	4	1	2	0	7
	D	0	0	0	0	0
		18	1	4	0	

Control Group

		POST A	POST B	POST C	POST D	
	A	14	1	0	0	15
PRE	B	4	0	0	0	4
	C	3	0	1	0	4
	D	0	0	0	0	0
		21	1	1	0	

B. % of students correct (chance level: 25%)

Computer Group Pre Test	Computer Group Post Test	Control Group Pre Test	Control Group Post Test
39% n.s.	78% a*	65% a*	91% a*

C. Did students improve significantly?

Computer Group

		POST Correct	POST Incorrect
PRE	Correct	9	0
	Incorrect	9	5

Control Group

		POST Correct	POST Incorrect
PRE	Correct	14	1
	Incorrect	7	1

Binomial: p=.002 *
(*=significant progress)

Binomial: p=.035 *

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	39	26	n.s.

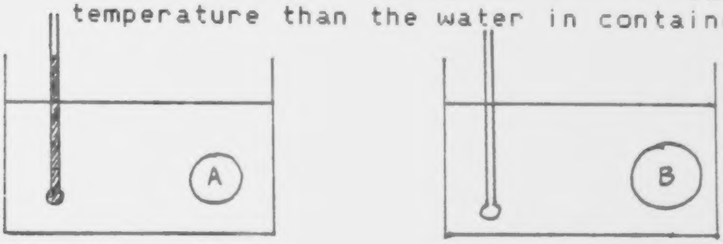
Table 16-19

Question 19: Two steel balls have a 60°C temperature. One weighs 300g and the other weighs 600g. They are both placed in identical containers of cold water. Which of the following is true:

A) The water in the two containers will reach the same temperature.

B) The water in container A will reach a higher temperature than the water in container B.

C) The water in container B will reach a higher temperature than the water in container A.



Correct Answer: C

A. Number of students choosing each answer:

Computer Group

		POST			
		A	B	C	
PRE	A	2	2	3	7
	B	2	0	2	4
	C	3	1	8	12
		7	3	13	

Control Group

		POST			
		A	B	C	
PRE	A	2	3	3	8
	B	0	2	0	2
	C	4	1	8	13
		6	6	11	

B. % of students correct (chance level: 33.3%)

Computer Group		Control Group	
Pre Test	Post Test	Pre Test	Post Test
52% a*	57% a*	57% a*	48% n.s.

C. Did students improve significantly?

Computer Group

		POST	
		Correct	Incorrect
PRE	Correct	8	4
	Incorrect	5	6

Binomial: p=.5 n.s.

Control Group

		POST	
		Correct	Incorrect
PRE	Correct	8	5
	Incorrect	3	7

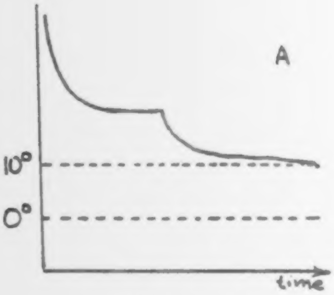
Binomial: p=.36 n.s.

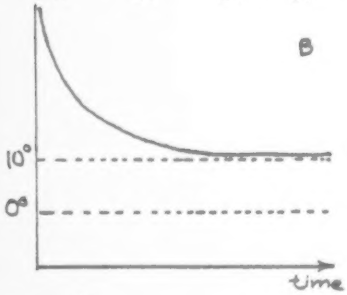
D. Did the computer group improve significantly more than the control group?

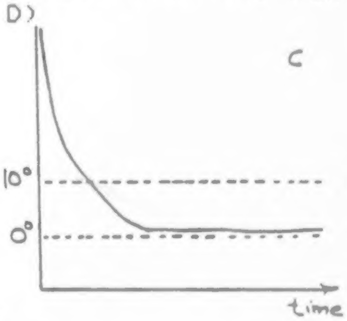
	Computer	Control	Difference
% Improved:	4	-9	n.s.

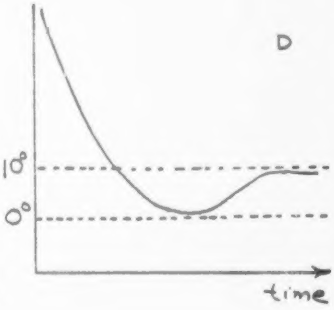
Table 16-20

Question 20: You take a test tube containing hot liquid wax and place it into a beaker of cold water ($10^{\circ}C$). After a while, the wax freezes. You are recording the temperature of the wax. Which graph best represents the temperature of the wax: A) B) C) or D)









Correct Answer: A

A. Number of students choosing each answer:

Computer Group

		POST A	POST B	POST C	POST D	
PRE	A	0	1	2	0	3
	B	0	1	2	0	3
	C	1	6	6	0	13
	D	0	1	3	0	4
		1	9	13	0	

Control Group

		POST A	POST B	POST C	POST D	
PRE	A	0	0	1	0	1
	B	0	2	2	0	4
	C	1	3	7	3	14
	D	1	1	1	1	4
		2	6	11	4	

B. % of students correct (chance level: 25%)

Computer Group Pre Test	Computer Group Post Test	Control Group Pre Test	Control Group Post Test
13% n.s.	4% n.s.	4% n.s.	9% n.s.

C. Did students improve significantly?

Computer group

		POST Correct	POST Incorrect
PRE	Correct	0	3
	Incorrect	1	19

Binomial: p=.31 n.s.

Control Group

		POST Correct	POST Incorrect
PRE	Correct	0	1
	Incorrect	2	20

Binomial: p=.5 n.s.

D. Did the computer group improve significantly more than the control group?

	Computer	Control	Difference
% Improved:	-9	4	n.s.

Table 16-21

Table 17

Multiple Choice Test - Classroom Study 1986.
Summary of Results

	Pre Test to Post Test Change		Group Showing More Improvement
	Computer Group	Control Group	
Q1	p*	p*	Computer
Q2	p*	p*	Control
Q3	p*	p	Computer*
Q4	p	p*	Control*
Q5	p*	p*	Computer
Q6	p	r	Computer
Q7	p	p	No Difference
Q8	p	r*	Computer
Q9	r	p	Control
Q10	p*	p	Computer*
Q11	p	p	Computer*
Q12	p*	p	Computer
Q13	r	p	Computer
Q14	r	r	Control (less regression)
Q15	p	p*	Control*
Q16	r	p	Control
Q17	p	r	Computer
Q18	p*	p*	Computer
Q19	p	r	Computer
Q20	r	p	Control

p: progress
r: regression
*: significant at the .05 level

TABLE 18

Results of the Multiple choice Conceptual Test. 1986 Study.
The numbers represent the percentages of students in the computer and in the control group, who chose each answer for each question on the pretest and on the posttest.

ANSWER CHOICE

QUESTION	A	B	C	D	E	F	G	H	I	J	K
1	68 *77*	33 *23*									
	91 *96*	9 *5*									
2	29 *40*	71 *83*	0 *20*								
	100 *0*	100 *0*	50 *100*								
3	33 *71*	7 *24*	0 *12*	48 *71*	7 *24*	0 *18*	27 *29*	7 *18*	0 *0*	13 *42*	
	38 *63*	33 *42*	24 *23*	67 *45*	24 *42*	10 *14*	19 *32*	5 *18*	10 *14*	33 *14*	
4	**Ba**	**Bb**	**Bc**	**Bd**	**Ca**	**Cb**	**Cc**	**Cd**	**Ce**	**Cf**	**Cg**
	24 *32*	38 *32*	38 *45*	0 *4*	5 *5*	5 *23*	0 *5*	38 *42*	10 *18*	0 *18*	19 *42*
	53 *50*	59 *36*	13 *36*	0 *13*	0 *4*	22 *26*	4 *9*	31 *26*	22 *18*	0 *13*	13 *18*
5	**Ba**	**Bb**	**Bc**	**Ca**	**Cb**						
	14 *18*	59 *77*	38 *42*	33 *14*	5 *9*						
	9 *26*	77 *78*	36 *9*	22 *18*	4 *26*						
6	0 *50*	100 *75*									
	50 *0*	75 *100*									
7	50 *50*	10 *17*	30 *83*	10 *45*	30 *22*	25 *50*					
	50 *67*	30 *22*	50 *83*	25 *40*	15 *6*	45 *45*					
8	38 *83*	8 *22*	38 *66*	48 *22*							
	77 *71*	18 *23*	67 *48*	28 *23*							
9	57 *41*	76 *68*	19 *18*	24 *68*	33 *50*	48 *14*	19 *82*	19 *32*	52 *46*	24 *32*	14 *41*
	78 *30*	83 *52*	9 *30*	22 *39*	46 *44*	57 *17*	61 *52*	26 *26*	74 *39*	22 *17*	17 *22*

Table 18-1

ANSWER CHOICE

QUESTION	A	B	C	D	E	F	G	H	I	J
10	29 *32*	38 *55*	24 *9*	38 *50*	10 *36*	52 *73*				
	70 *57*	61 *57*	22 *9*	26 *26*	26 *13*	65 *70*				
11	85 *100*	30 *5*	10 *0*	80 *91*						
	83 *91*	48 *4*	13 *9*	65 *83*						
12	91 *71*	5 *0*	10 *5*	48 *48*	5 *29*	81 *76*				
	65 *70*	26 *9*	22 *13*	65 *44*	0 *17*	74 *61*				
13	19 *23*	24 *4*	29 *23*	52 *23*	10 *50*	14 *23*				
	41 *26*	27 *9*	32 *17*	41 *22*	5 *48*	5 *48*				
14	78 *63*	53 *28*	9 *9*	33 *23*	19 *9*					
	70 *100*	31 *4*	13 *13*	4 *9*	18 *9*					
15	48 *33*	33 *62*	33 *43*	62 *67*						
	65 *61*	30 *39*	39 *57*	70 *52*						
16	33 *50*	10 *18*	19 *14*	67 *36*						
	44 *26*	30 *44*	17 *22*	39 *57*						
17	38 *64*	19 *18*	10 *23*	10 *5*	43 *36*	19 *5*	43 *36*			
	39 *52*	48 *26*	22 *17*	9 *9*	57 *57*	13 *26*	35 *49*			
18	71 *68*	10 *18*	10 *14*	5 *5*	76 *68*	43 *14*				
	91 *61*	13 *9*	0 *9*	0 *13*	48 *57*	70 *52*				
19	52 *57*	38 *76*	38 *52*	19 *38*	33 *43*	5 *5*	38 *19*	0 *5*	48 *0*	
	65 *74*	35 *57*	61 *83*	13 *48*	39 *48*	17 *13*	39 *44*	13 *22*	22 *22*	

key:

1 2

----

3 4

1. pre-interview for control group
2. post-interview for control group
3. pre-interview for computer group
4. post interview for computer group

Number Of People To Answer The Questions

QUESTION	CONTROL PRE	CONTROL POST	COMPUTER PRE	COMPUTER POST
1	21	22	23	23
2	7	5	2	2
3	14	17	21	21
4	21	22	23	23
5	21	22	23	23
6	21	22	23	23
7	20	19	19	18
8	13	10	10	13
9	21	22	23	23
10	21	22	23	23
11	21	22	23	23
12	21	22	23	23
13	21	22	23	23
14	21	22	23	23
15	21	22	23	23
16	21	22	23	23
17	21	22	23	23
18	21	22	23	23
19	21	22	23	23

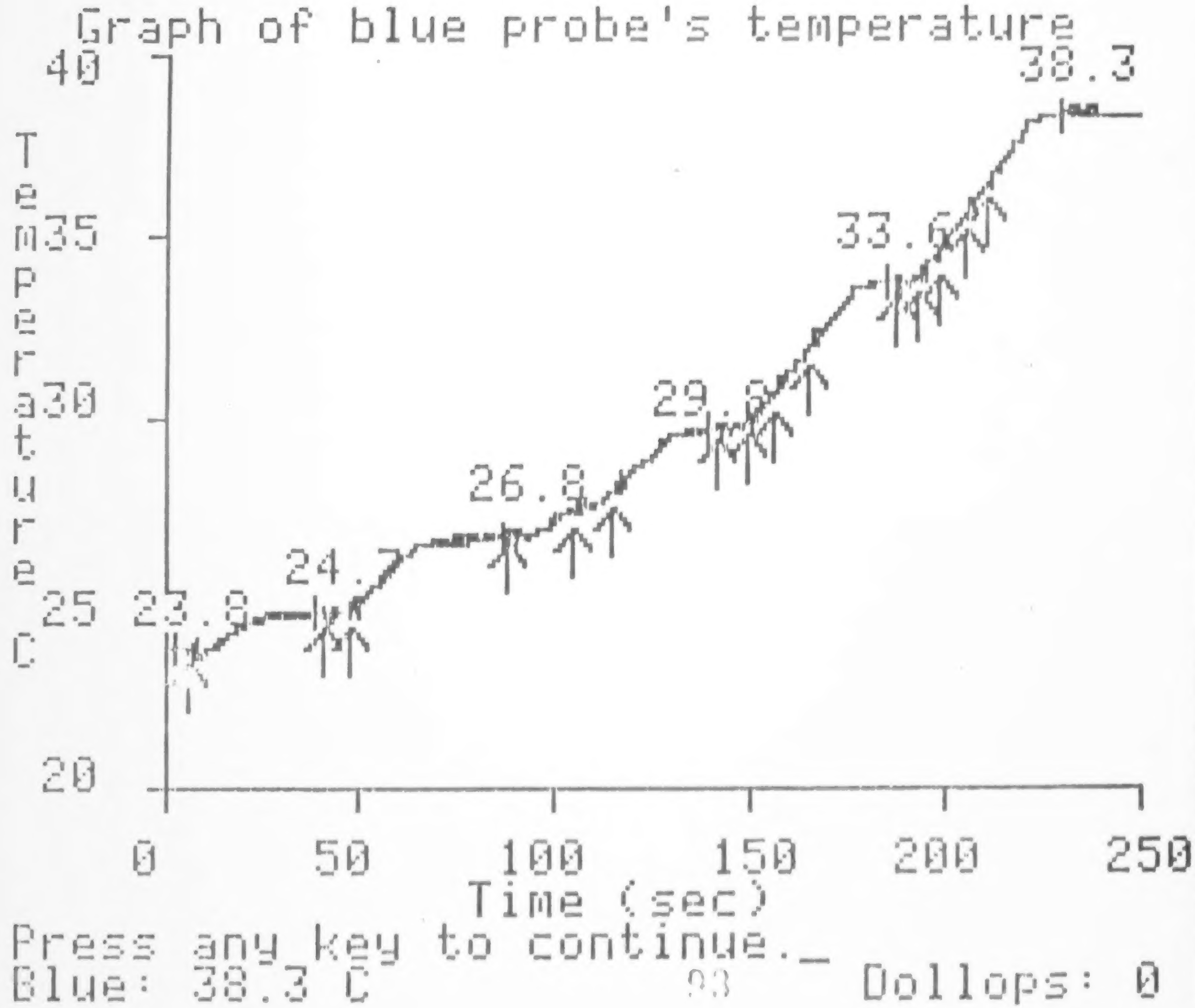
Table 18-3

TABLE 19

1986 Classroom Study. Multiple-Choice Conceptual Test.
Modal Answers (%).

		QUESTION									
		1	2	3	4	5	6	7	8	9	10
Computer	PRE	A(91%)	A(100%)	D(62%)	A(60%)	B(68%)	A(68%) B(68%)	A(53%) C(53%)	A(73%)	B(83%)	A(70%)
	POST	A(96%)	C(100%)	A(62%)	A(45%)	B(74%)	B(100%)	C(81%)	A(64%)	B(52%) G(52%)	F(70%)
Control	PRE	A(67%)	B(63%)	D(50%)	B(40%)	B(56%)	B(100%)	A(47%)	A(40%) C(40%)	B(76%)	F(52%)
	POST	A(77%)	B(83%)	A(71%) D(71%)	A(40%) C(40%)	B(74%)	B(67%)	C(78%)	A(70%)	G(82%)	F(73%)

		QUESTION								
		11	12	13	14	15	16	17	18	19
Computer	PRE	A(83%)	F(74%)	A(41%) D(41%)	A(71%)	D(70%)	A(44%)	E(57%)	A(91%)	A(65%)
	POST	A(91%)	A(70%)	E(48%) F(48%)	A(95%)	A(61%)	D(57%)	E(57%)	A(61%)	C(83%)
Control	PRE	A(85%)	A(91%)	D(52%)	A(85%)	D(62%)	D(67%)	E(43%)	E(76%)	A(52%)
	POST	A(100%)	F(76%)	E(50%)	A(64%) B(64%)	D(68%)	A(50%)	A(64%)	A(68%) E(68%)	B(76%)



```
Press any key to continue._
Blue: 38.3 C                    Dollops: 0
```

Figure 3.

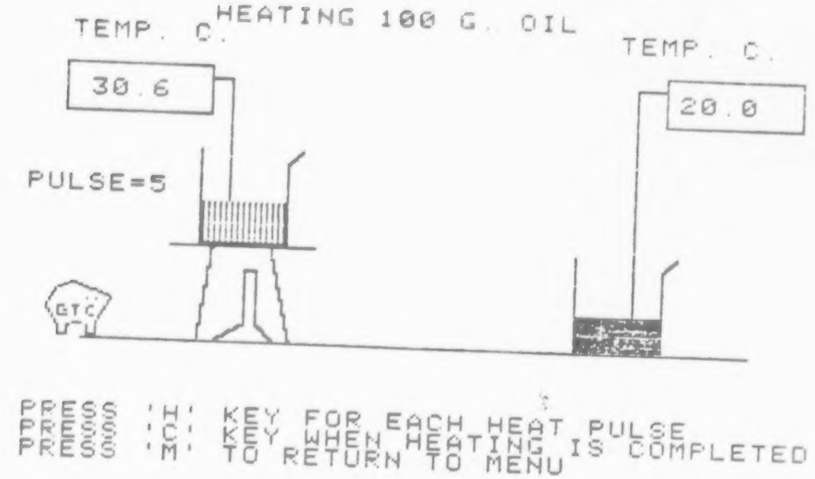

TEMP. C.
30.6
PULSE=5
GTC
TEMP. C.
20.0

Fig. 1A

HEATING 100 G. OIL

PRESS 'H' KEY FOR EACH HEAT PULSE
PRESS 'C' KEY WHEN HEATING IS COMPLETED
PRESS 'M' TO RETURN TO MENU

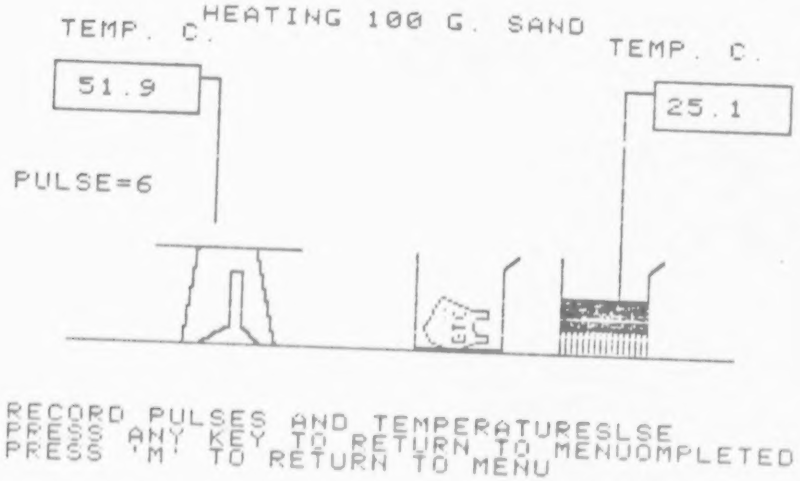

TEMP. C.
51.9
PULSE=6
GTC
TEMP. C.
25.1

Fig. 1B

HEATING 100 G. SAND

RECORD PULSES AND TEMPERATURESLSE
PRESS ANY KEY TO RETURN TO MENUOMPLETED
PRESS 'M' TO RETURN TO MENU

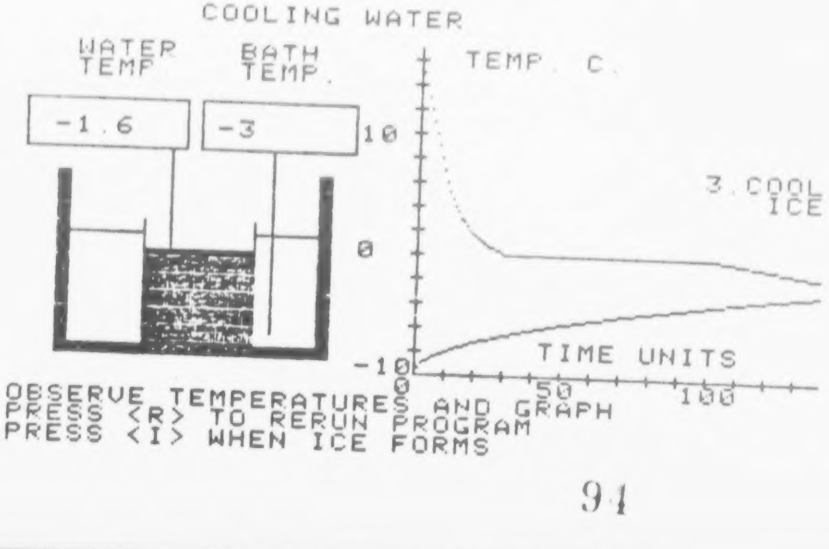

WATER TEMP
BATH TEMP.
-1.6
-3
TEMP. C.
10
0
-10
3. COOL ICE
TIME UNITS
0
50
100

Fig. 2

COOLING WATER

OBSERVE TEMPERATURES AND GRAPH
PRESS <R> TO RERUN PROGRAM
PRESS <I> WHEN ICE FORMS

APPENDIX 1

Multiple choice test. 1985 study.

TEST

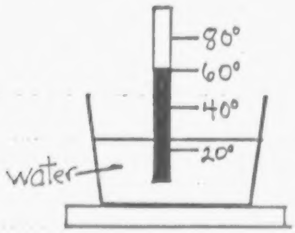
Do not write on these sheets. Write your answers on a separate sheet.

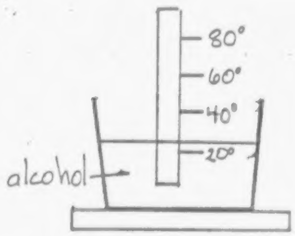
1.A quantity of heat is put into 100g of water and causes that water's temperature to rise 20°C. If the same quantity of heat is put into 200g of water what temperature rise will it cause?

A) 10°C B) 20°C C) 30°C D) 40°C

2. You start with the same quantity of water and alcohol both at room temperature. You heat them on identical hot plates for the same amount of time. The temperature of the water reaches 60°C. What temperature will the alcohol reach?

A)60°C B)more than 60°C C)less than 60°C





3.Two units of heat are put into 100g of water at 25°C (Beaker 1) and four units of heat are put into 200g of water at 50°C (Beaker 2.) Which of the following is true?

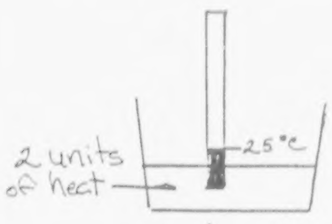
A)The temperature change in beaker 1 is the same as the temperature change in beaker 2.

B)The temperature change in beaker 1 is less than the temperature change in beaker 2

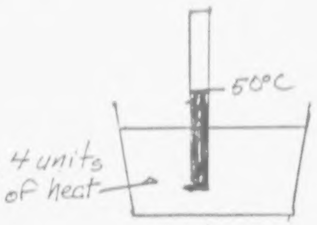
C) The temperature change in beaker 1 is more than the temperature change in beaker 2

D)The final temperature is the same in beaker 1 and in beaker 2

E)None of the above



Beaker 1



Beaker 2

4.Temperature is

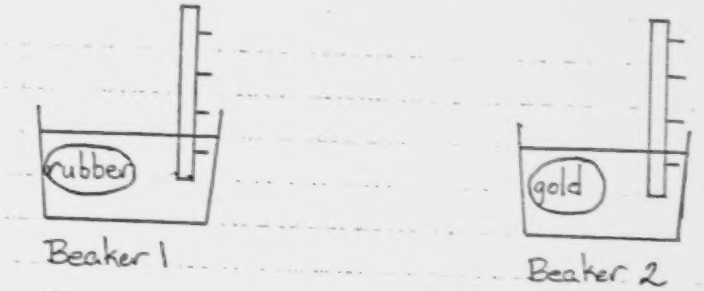
A) measured on a thermometer
B) the measure of heat
C)the specific heat of a substance
D)the total energy of the molecules of a substance
E)both A) and B)

5.You put the same amount of heat into equal masses of rubber and gold. The temperature of the rubber increases by 10°C. The temperature of the gold increases by 100°C. Which of the following is true?

A) Gold has a higher specific heat than rubber
B) Rubber has a higher specific heat than gold.
C) Gold and rubber have the same specific heat.
D) One cannot tell from the information given whether gold or rubber has a higher specific heat

6.After heating the pieces of rubber and gold as described in question 5 you drop them in identical containers of cold water. The piece of rubber is in beaker 1 and the piece of gold is in beaker 2. Which of the following is true?

A)The final temperature in beaker 1 will be higher than the final temperature in beaker 2
B)The final temperature in beaker 2 will be higher than the final temperature in beaker 1
C)The final temperature in beaker 1 and in beaker 2 will be equal.



7. 200g of iron and 200g of aluminum are both heated to 100°C. They are placed in identical containers of cold water. The hot iron causes the temperature of the water to rise 10°C. By how much will the hot aluminum cause the water's temperature to rise?

A)5°C B)10°C C)20°C D)40°C

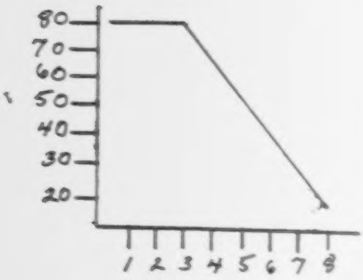
8) 200g of water at 100°C is added to 200g of water at 50°C. What will the final temperature of the mixture be?

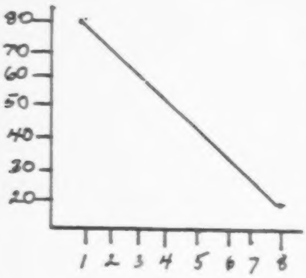
A)25°C B)50°C C)75°C D)100°C E)150°C

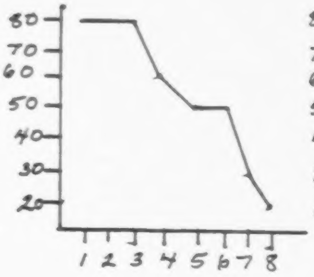
9) Which graph below best represents the data in the following table:

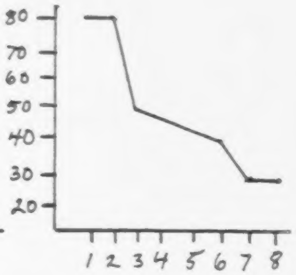
A) B) C) D)

Time(minutes)	1	2	3	4	5	6	7	8
Temperature(C)	80°	80	80	60	50	50	30	20



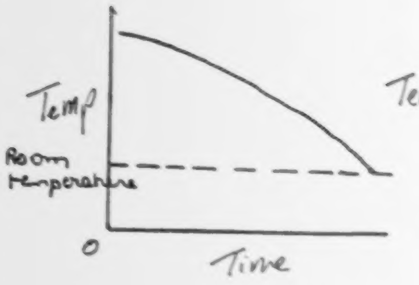


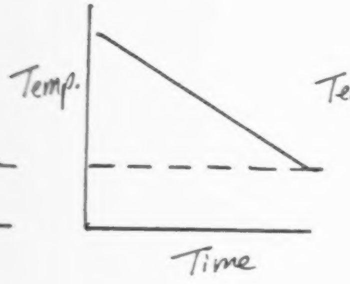


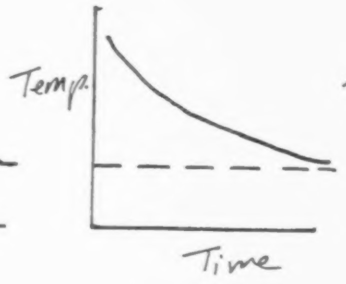


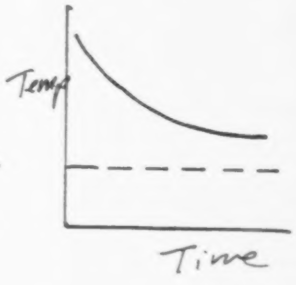
10) Which of the following graphs best represents how the temperature of a liquid changes over time when the liquid cools without freezing?

A) B) C) D)







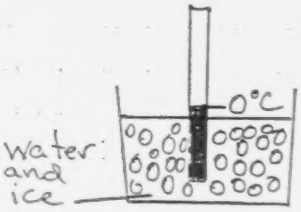


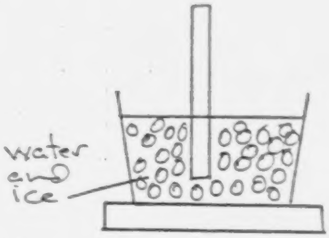
11.A lump of hot iron raises 100g of water from 30°C to 90°C. An identical lump of hot iron will raise 100g of water from 50°C to

A)90°C B)100°C C)110°C D) none of the above

12.The thermometer is in a beaker of ice and water. It reads 0°C. We put the beaker on a hot plate for a minute. After that time there is still some ice left in the beaker. What does the thermometer read?

A) Less than 0°C
B) 0°C
C) More than 0°C





APPENDIX 2

Questions asked during the interview. 1985 Study.

Interview Questions

What will happen to the level of alcohol in the tube when the flask is placed in the hot water? Why?

What is happening to make the level rise (suppose you could see inside with a very powerful microscope)?

Will the alcohol stop rising up the tube at some point? Where? Why?

Why doesn't it keep rising (since the water is still hot)?

What if we added more hot water?

What if we used hotter water?

What if there was a different liquid in the flask?

Suppose we have two containers of snow and we pour one cup of hot water into the first container and two cups into the second, which will melt more snow? Why?

If more does more in one case-like melting more snow- then why doesn't it do more in another case-like heating more alcohol?

Do you think there is a problem here?

Can you explain it?

(two different sized containers of water)

Does it make sense to say there is "more heat" in one of these containers?

Can you explain that?

If we put thermometers into each container would they be the same or different?

What is heat? Can you define it?

Where does it come from?

Can it be measured? How?

(How does a thermometer work?)

(What is temperature?)

If you leave hot water by itself, what happens? How?

Where does the heat go?

What will happen when the flask of alcohol is placed in the container of ice? Why?

What is going on in there (if you could see inside with a very powerful microscope)?

Will it (the temperature) stop going down at some point? Where? Why?

Why doesn't it go lower (since the ice is still cold)?

What if we added more ice?

Can we make the ice colder? How?

Would colder ice make a difference?

What would happen if there was a different liquid in the flask?

What would cool a drink more, a big ice cube or a small one? Why?

Why does more ice cool more in this case but not in the other case (with the alcohol)?

Do you think there is a problem here?

Can you explain it?

Is a big ice cube as cold, less cold or colder than a small ice cube? Why?

If we put thermometers into each ice cube would the readings be the same or different?

What is cold? Can you define it?

Where does it come from?

Can it be measured? How?

(two different sized pieces of steel and two identical containers of water - diagram)

After heating the two pieces of steel on a hot plate for five minutes, we drop them into the two containers of water - will one sizzle more? Which one? Why?

If we read the thermometers in the water, will they be the same or different? Why?

If we put thermometers into each piece of steel, what will they read? Why?

If we put a flask of alcohol and a flask of water into a hot water bath, what will happen?

Will one heat up faster?
Will one go higher?
Why is there a difference?

What happens if we put a flask of cold water and a flask of warm water into the same hot water bath? Why?

Why is there a difference?

If you put an ice cube into a glass of hot water, will it melt? Why?
If you put an ice cube into a glass of cold water, will it melt? WHY?
Do you need heat to melt something?
Where is the heat in a glass of cold water?

Is there a difference between heat and temperature (can two things be the same temperature and one have more heat)?

Can you explain the difference?

APPENDIX 3

Example of interview. 1985 Study.

Q: ...alcohol in water...what happens?
A: It expands
Q: How?
A: By forming a gas...bubbling...it boils.
Q: What happens to the alcohol in the tube?
A: It rises.
Q: How does the hot water make the alcohol expand and rise?
Q: The molecules react to the hot water and get larger...they keep splitting apart... there's millions of them...and it expands.

Q: Will the alcohol stop rising?
A: No, it will keep going because there's no end to how many times the molecules can split so it keeps getting larger and larger.

Q: Suppose it does stop, how would you explain that?
A: Maybe the molecules tire out and can't go anymore...after splitting for a while they might die and stop because of overuse. There's a point where they can't expand anymore.

Q: What if we used more water?
A: That would make no difference...it's the same heat...just more water.
Q: What do you mean by the "same heat"?
A: It's the same temperature it might rise faster, but not higher.

Q: What if we used hotter water?
A: Then it would rise faster...and maybe higher.

Q: ...snow example...which melts more?
A: Two cups because there's more...it covers more area...touches more snow.

Q: If more melts more snow then why doesn't more heat more alcohol...it's also covering more?
A: Maybe snow reacts to hot water more than the alcohol does. It acts immediately. Maybe it's because the two things -snow and alcohol- are just different.

Q: ...two different sized containers of hot water...does it make sense to say one has more heat?
A: There might be more circulating in the [illegible] container...if you touch the containers they'd be the same, though.
Q: What do you mean by more "circulating"?
A: There's more heat in the larger container because there's more area...it's just that there's more

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water. They are at the same temperature.
Q: What is heat?
A: It is caused from reactions like rubbing two things...like the molecules rubbing against each other...friction.
Q: How do they start rubbing together in the first place?
A: If they are upset in some way that might start the friction...which is heat...if you shake them for example.
Q: Where does heat come from?
A: From the molecules splitting and rubbing against each other.

Q: ...alcohol in ice...what happens?
A: The temp. goes down because the ice acts upon the alcohol and causes it to get cold.
Q: How does that happen?
A: By freezing it...freezing the particles...molecules... causing them to stand still rather than move around.
Q: If you looked inside with a microscope, what would you see?
A: You would see the molecules slowing down.

Q: Will the temp. stop going down?
A: Yes, because there's a certain temp. in the ice and the temp. in the alcohol will level off to that. The alcohol will get to the maximum coldness of the ice.
Q: If there was a thermometer in the ice and the alcohol what would they read?
A: They would be different...the ice is colder because the alcohol won't freeze.
Q: What if the alcohol could freeze?
A: They'd be in the same temperature.
Q: What if we added more ice?
A: Nothing would happen because more ice is at the same temp. as the other ice.
Q: What if we used colder ice?
A: That would make the alcohol colder...bring it to a lower temperature.

Q: ...drink example...which cools it more?
A: The bigger ice cube because there's more of it to cool the entire drink...there's more mass.
Q: What's important about the mass?
A: It means ther's more of it to cool something faster...it reaches more of the drink faster.
Q: Does it make it colder?
A: No.
Q: When you want a cold drink do you put a lot or a little ice in it?
A: A lot, so I guess more ice makes it colder.

Q: If more ice makes the drink colder, why doesn't more make the alcohol colder?
A: It's like the snow example...they're two different things so they react differently.

Q: What is cold?
A: When the molecules stand still rather than move around quickly and causing friction.
Q: Where does cold come from?
A: I'm not sure.

Q: ...steel example...which sizzles more?
A: The bigger piece because it would touch more water at one time.
Q: If we read the thermometers in the water, what would they read?
A: The one with the bigger piece would be higher because it's heating more particles of water faster. Eventually they might be the same because the smaller might catch up.
Q: Does the size of the steel make a difference?
A: No.

Q: ...alcohol and water in hot water...what happens?
A: Both will go up.
Q: Will one go higher?
A: No.
Q: Will one go faster?
A: Yes, the water will...because it's the same thing as the hot water.
Q: Why will they stop at the same place?
A: Because they both get as hot as the hot water.

Q: ...cold and warm water in hot water...what happens?
A: The warm water rises faster but both will end up at the same point.
Q: Why does the warm water rise faster?
A: The cold has to go from warm to hot...the warm one just has to get hot.
Q: So the cold will take longer because it has to go farther...but does it actually rise at a faster rate?
A: It just takes longer...they rise at the same speed.

Q: If you put an ice cube in hot water, will it melt?
A: Yes because the hot water acts on the ice cube more than the ice acts on the water...there's more of the water than of the ice.
Q: If you put ice in cold water, will it melt
A: Yes, the ice will go up to the water's temp. There's heat in the cold water compared to the ice cube. It's warmer than the ice cube.

Q: Is there a difference between heat and temperature?

A: Temperature is a number...it measures...heat and cold are just there. Temperature measures heat and cold.

APPENDIX 4.

Classification of answers to Question 1: "Why does the level rise?

A. Molecule arguments

A1. Molecules in water are faster; they strike the molecules of alcohol and make them move fast

A2. Molecules speed up and need a place to go; they speed up because there is an increase in kinetic energy

Molecules speed up because adding heat is adding energy

Molecules speed up and need a place to go because you are adding heat which is a flow of energy

Molecules speed up and need a place to go because adding heat gives them energy

Molecules push each other up because there is an increase in kinetic energy

A3. Molecules move faster and need a place to go

Molecules bounce off each other and spread further apart

Molecules at bottom move faster and push the slow ones at the top

Molecules move faster and push each other up [and the pressure increases]

A4. Molecules move faster

Molecules move faster; don't know why the level rises

Air molecules [above the alcohol] spread, expand, move faster

Molecules enlarge/divide

Molecules expand

B. Force arguments

Heat pushes the level/ Heat exerts pressure/ Hot water pushes the level/ Air above the alcohol pushes the level/ Pressure inside (No detail)/ Energy pushes the level up

C. Other arguments

Alcohol escapes from heat/ Heat rises/ Evaporation/ Bubbles rise/ Alcohol rises above the water level

Boiling

Like a thermometer

APPENDIX 5.

Classification of answers to Question 3: "Why does the level stop?"

Evidence for thermal equilibrium

Equalization.

Speed of alcohol molecules is equal to speed of water molecules.
Water cannot make alcohol hotter than itself
Water gives a certain degree of heat to the alcohol;
Water gives a certain temperature heat to the alcohol
Stops when water and alcohol have the same heat
Water cannot give more heat than it has
Alcohol and water are at the same temperature
Alcohol is at constant temperature
Alcohol gets hotter, water gets cooler, it balances out

Transfer only arguments

Stops when all the heat is transferred

Water does not give extra heat to the alcohol; no more heat goes in; no energy to heat it up more

All the energy it has to give; can only give so much; no more energy goes in

Temperature and transfer arguments

Temperature in water is equal to temperature of alcohol; there is no more transfer of heat

Temperature in water is equal to temperature of alcohol; there is no more transfer of energy

No evidence for thermal equilibrium

Molecules move at the same speed and do not need any more room

Molecules go as fast as they can; molecules get used to energy of the water; heat cannot make the atoms move faster

Molecules are as far apart as possible

Molecules are as big/divided as they can be

Heat has limited power/force; air pressure is limited; air pressure disappears/ no more pressure/ gets too tightly compressed

Counteracting force: air pushing through the tube/ gravity

Heat is not as hot at the top
Heat is constant; no increase of heat
There is only a certain amount of heat in the water
No other heat is applied to make [the alcohol] hotter
Water is at a constant temperature
It is less hot at the top, so alcohol at the top cools and stops
Energy is constant; no increase in energy
No energy to heat it up more

Alcohol gets used to the water
It equals out
Nothing to speed it up anymore

Stops because it is like a thermometer

Evidence against equilibrium

It is as hot as it can be (in the intrinsic sense)
Reaches a certain point (does not know what that point is)
Stops because starts boiling

Alcohol stops at a lower temperature because it has a lower specific heat

APPENDIX 6

Categorization of answers to Question 4: "If we pour more hot water around the flask, will the level rise?"

Evidence for equilibrium

The level will not rise because:

"The heat does not get any greater." "It is the same heat." You are not adding more heat, just more water."

"The alcohol is already at the temperature of the water."

"The second water is at the same temperature as the first."

"There is more heat because there is more volume but the temperature is the same."

"There is no more heat for it to get." "There is no more heat for it to get because the water is at the same temperature."

The level will rise because:

"More alcohol is covered therefore all the molecules have the same heat."

No evidence for or against equilibrium (neutral)

The level will not rise because:

"The molecules are as far apart as possible."

"The molecules are as big/divided as can be."

"There is not more energy, just more water."

The level will rise because:

"More is covered."

Evidence against equilibrium

The level will rise because:

"The molecules spread more."

"There is more force/pressure."
"More heat goes into the alcohol."
"More water makes the alcohol hotter."
More water is hotter

The level will rise higher (no explanation)
The level will go faster
The level will keep going
The level will rise but "at a certain point it won't get any hotter; it's its highest point."

APPENDIX 7

Categorization of answers to Question 5: "If we pour hotter water around the flask, will the level rise?"

Evidence for equilibrium

The level will rise higher because:

"The molecules in the hotter water are faster, so the molecules in the alcohol are faster."

"The level will rise until the alcohol has the same heat as the water."

"The level will rise until the alcohol reaches the same temperature as the hotter water."

Inconclusive arguments (neutral)

The level rise higher because:

"The molecules spread out more/move faster."

"There is more force/energy to push the level up."

"The water is hotter."

"More heat transfers/is added to the alcohol." "More energy transfers/is added to the alcohol"

"The is more heat/more energy."

The level will go higher
The level goes higher and stops
The level goes higher until equals out
The level will go faster

Evidence against equilibrium

The level will rise faster but not higher
The level keeps going but faster
The alcohol keeps boiling

APPENDIX 8

Categorization of answers to the Beaker question: "Which has more heat, a small or a large beaker of [the same] hot water?"

Heat intensive. "They have the same heat because they have the same temperature/because it is the same water."

Heat and temperature undifferentiated (volume matters.)"The bigger one has more heat." Experimenter: "Do they have the same temperature?" Student: "No, the larger one is hotter."

Conflict/Confusion

Conflict beteen heat intensive and heat extensive. Student: "The larger one has more heat." Experimenter: "Do they have the same temperature?" Student: "Yes, so they have the same heat after all."

Incomplete understanding of the difference between heat and temperature. Student: "More water can hold heat longer because there is more heat that has to come out before it cools down. Experimenter: "Does it mean one has more heat?" Student: "In the smaller one the heat is more concentrated but the big one has more heat." Experimenter: " If there were a thermometer in each container, what would they read?" Student: " The same temperature." Experimenter: " If they are the same temperature, what do you mean by more heat?" Student: " It willhold the heat longer because there is a larger amount." Experimenter: " What is heat?" Student: " The average kinetic energy of the particles in matter." Experimenter: " What does that mean?" Student: " [] Heat is how fast the particles are moving." Experimenter: " Can heat be measured?" Student: " Yes, with a thermometer." Experimenter: " If the two containers of water were the same temperature and one had more heat, how is the thermometer measuring the heat?" Student: " Heat and temperature are not the same. Temperature is a measure of how fast the molecules are moving in general. I am not sure what the difference is but temperature does not measure heat."

Heat extensive, no explanation. Student: "The larger one has more heat." Experimenter: "Do they have the same temperature?" Student: "Yes." Experimenter: "Is there a problem, that the larger one has more heat but the same temperature?" Student: "No."

Heat has degree and amount. Student: "The larger one has more heat." Experimenter: "Do they have the same temperature?" Student: "Yes." Experimenter: "Is there a problem, that the larger one has more heat but the same temperature?" Student: "No, the larger one has more of the same temperature heat."

Differentiation Student: "The larger one has more heat." Experimenter: "What do you mean by more heat?" Student: "A greater volume of heat." Experimenter: "If we had a thermometer in each, what would they read?" Student: "Same temperature." Experimenter: "If two things are the same temperature and one has more heat, how are heat and temperature related?" Student: "Temperature is the average amount of heat per unit area...so something with a bigger area has more heat." Experimenter: "Can heat be measured?" Student: "It is the temperature multiplied vy the mass multiplied by the specific heat...that gives you the amount of heat in Joules."

APPENDIX 9

Categories used to classify answers to the Steel questions.

Heat Intensive.

A. Heat purely intensive, no effect of volume. "Both have the same temperature because they receive the same heat. They have the same effect on the water because they are at the same temperature.

B. Heat intensive; effect of source depends on its volume. "They reach the same temperature because they were on the heat the same amount of time. The bigger one makes the water hotter because they have the same temperature and there is more of it."

C. Heat intensive, intuitive notion that the small one gets hotter, no effect of source volume. "The smaller one gets hotter because it is easier to heat up, and it makes the water hotter because it was hotter."

D. Heat intensive, intuitive notion that the small one gets hotter , effect of source depends on its volume. "The smaller one gets hotter because there is less area to heat; it is smaller, it heats faster. They heat the water the same because the small one has heated faster but it is smaller, it evens out in heating the liquid."

Non differentiation.

Experimenter: "The bigger one will be hotter because there's more heat stored in it because it is larger. The water with the bigger piece will have a higher temperature because the heat from the steel made the water warmer."

Incomplete differentiation.

A.Student: "The bigger one heats the water more because there's more heat in it." Experimenter: "Did it get more heat from the hot plate in the same amount of time?" Student: "Yes. It has more of a mass, so it can absorb more heat. The temperature would be the same but the bigger one has more heat." Experimenter: "So , does temperature measure heat?" Student: "It measures it but not how much there is."

B.Student: "The big one has more heat in it; there is a certain number of atoms in each piece of steel, the bigger one has more, so when they rub together they produce more heat." Experimenter: "What will the readings in the water be?" Student: "The one with the bigger piece would be warmer because the bigger piece has more heat to give off." Experimenter: "If we had thermometers in each piece of steel, what would the readings be?" Student: "The small one would be higher because it takes less energy to heat it, so the amount of energy given off by the hot plate is more than enough to heat up the small one but not enough to heat the big one. So I want to change my answer. The smaller piece would make the water hotter because it has a higher temperature."

C.Student: "The temperature of the small one would be higher because the bigger one would take more heat to get at the temperature of the smaller one." Experimenter: " What would the thermometers in the the water read?" Student: "Probably the same, becasue... the [water with] the small one might be a little warmer...No, the size of the big one would probably make it equal."

Complete differentiation.

A. This student uses "heat" to refer to both heat and temperature, but they are distinct concepts. The solution is correct.

"The smaller one is hotter because there is less space to store heat, so it has more heat [meaning higher temperature]. The water baths will be at the same temperature because the two pieces have the same amount of heat in them."

B. These student believe that the two pieces have the same temperature because they are in equilibrium with the hot plate. Their justifications are based on distinct concepts.

"The bigger one has more heat, twice the energy. They are the same temperature because it is the same heat per volume."

"Once they reach the temperature [of the hot plate] they are going to stop going up. It takes less heat to get the small one to that temperature, so the big one will have more heat in it once it reaches that temperature. Once they get at it neither will absorb any more [heat] but while they were absorbing heat, the bigger one was taking more because it has more mass and volume so it needs more heat."

"The temperature of the water with the big piece is higher because the big piece has more energy to give off because it absorbed more. [The two pieces are at] the same temperature because temperature is just how hot they get, it's not how much heat is in them."

C. These students reach the correct solution by using the expert concepts "heat" and "temperature."

"They raise the temperature of the water the same because they both got the same amount of heat in the same time."

"The small one is hotter because the same amount of heat was given to both pieces and the smaller one has less space so it gets heated more. It takes less heat, less energy to heat it."

APPENDIX 10

Multiple-choice conceptual test. Adapted from the verbal interview.

The questions in this test are about physics. Please think carefully about each question and choose as many answers choices as you think apply. You can also write in your own answer in the space marked "other" on the answer sheet if you have other ideas about the question. We are not looking for "correct" answers and you will not be graded. We would just like to know your ideas about the various situations presented in this test. Please mark all answers on the answer sheet - do not write on this test.

Please pay close attention to the demonstration presented by your teacher.

1. Do you think the level of alcohol will stop rising up the tube?

   a. Yes (If you chose yes, please go to question 3)

   b. No (If you chose no, please go to question 2)

2. The level will not stop because:

a. The temperature is constant.

b. The heat is constant.

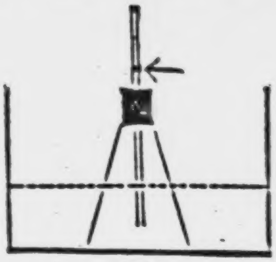
c. There is nothing to make it stop.

(Please go to question 4)

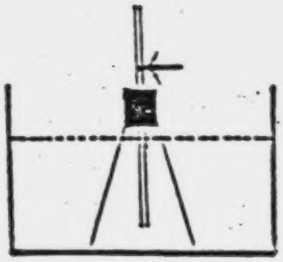
3. The level will stop because:

   a. After a while, the alcohol and the water have the same heat.
   b. The water gives only a certain degree of heat to the alcohol.
   c. The water gives a certain temperature heat to the alcohol.
   d. It stops when the alcohol and the water are at the same temperature.
   e. It stops because, after a while, no more heat goes in.
   f. It stops because, after a while, no more energy goes in.
   g. It stops because the heat has limited force.
   h. There is a limit to how hot the alcohol can get.
   i. The water stays at a constant temperature.
   j. It stops when the alcohol and the water molecules have the same kinetic energy.

4. Suppose we have the same situation as in question (1). Notice where the level stops in diagram (A). We then add more of the same water to the container. Will the level of alcohol go higher (as in diagram C) or stay the same (as in diagram B). Please circle (B) or (C). Then justify your choice by choosing one or more of the reasons listed below the diagram you chose.

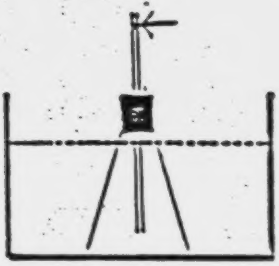


(A)



(B)

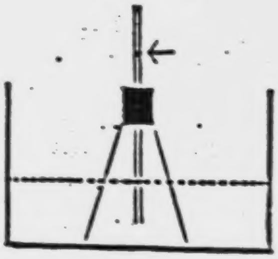
- a. It's not more heat, just more water.
- b. The water is still the same temperature.
- c. The alcohol is already at the temperature of the water.
- d. The alcohol is already as hot as it can be.



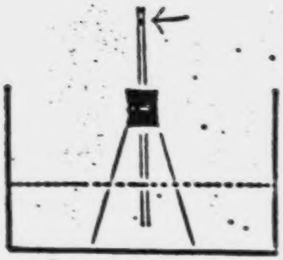
(C)

- a. It covers more.
- b. There is more heat in more water.
- c. More water is hotter.
- d. More heat goes into the the alcohol.
- e. There is more force or pressure.
- f. More water makes the alcohol hotter.
- g. More water gives off more heat.

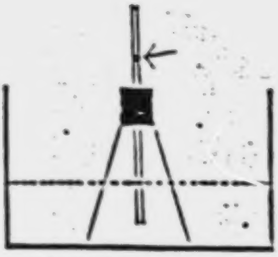
5. The water in containers (B) and (C) is hotter than the water in container (A). Will the level of alcohol go higher (as in B) or stay the same (as in C)? Please circle (B) or (C). Then justify your answer by choosing one or more of the reasons listed below the diagram you chose.



hot water
(A)



hotter water
(B)



hotter water
(C)

a. More force is applied.

b. The water gives the alcohol a greater amount of heat.

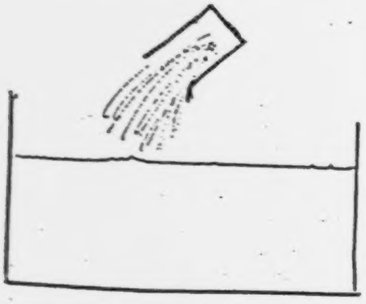
c. The heat given to the alcohol is more intense.

a. The alcohol is already as hot as it can be.

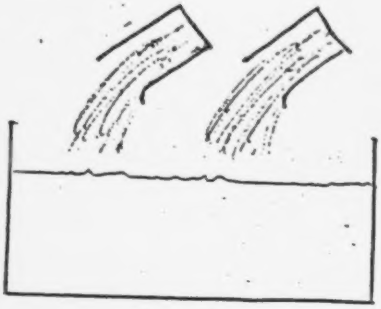
b. It's the same amount of water.

6+7. Suppose we have two very large boxes of snow. The boxes are the same size and contain the same amount of snow. We pour one cup of hot water into box (A) and two cups of hot water into box (B). If you think that more snow will be melted in box (B) go to question (7) on the next page. If you think the same amount will be melted in both boxes answer question (6) on this page.

(Note: All the snow is not melted in either box.)



(A)



(B)

6. The same amount will be melted because:

   a. It's the same heat.

   b. It's the same temperature.

(Please go to question 9)

7. More snow is melted in box (B) because:

   a. Two cups has more hot water although not more heat.

   b. Two cups of water stays hot longer than one cup.

   c. Two cups of water gives more heat to the snow although it's the same heat per volume of water.

   d. Two cups has more heat because there's more of the same temperature water.

   e. The same heat is applied to more snow.

   f. Two cups has more heat to give to the snow.

(please go to question 8)

(Skip question (8) if you chose diagram (C) in question (4)).

8. In question (7), if two cups of hot water melts more snow, why doesn't adding more water heat up the alcohol more?

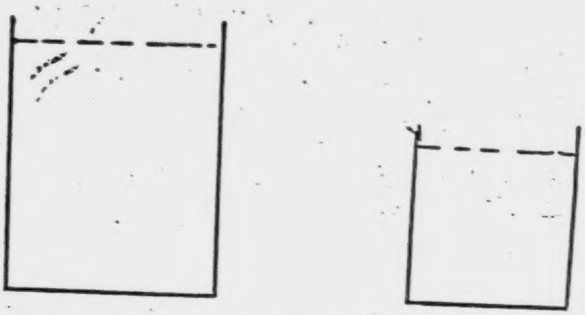
   a. The alcohol is at the temperature of the hot water while the snow cannot get to the temperature of the hot water until it is all melted.

   b. The snow cools the hot water so adding more hot water to snow makes a difference.

   c. More hot water can't give more heat to the alcohol because the alcohol is at the same temperature as the hot water, but more hot water can give more heat to the snow because the snow isn't at the temperature of the hot water.

   d. They're different substances.

9. Suppose we have two different sized beakers (see diagram) filled with hot water that was heated in the same pot.



Which of the following is true about this situation:

a. They have the same heat.

b. The big beaker has more of the same temperature water.

c. The smaller beaker has more heat because it's more compressed.

d. The big beaker of water gives off more heat.

e. The big beaker of water stays hot longer.

f. They have the same heat because the amount of water you have doesn't make a difference.

g. It takes more heat to heat up the bigger beaker of water.

h. The big beaker of water has more internal energy.

i. They are at the same temperature.

j. The big beaker of water has more heat.

k. There is more heat available in the big beaker of water because heat is proportional to mass.

10. The difference between heat and temperature is:

a. Temperature can be hot or cold but heat is just hot.

b. Heat is a flow of energy and temperature is the average kinetic energy.

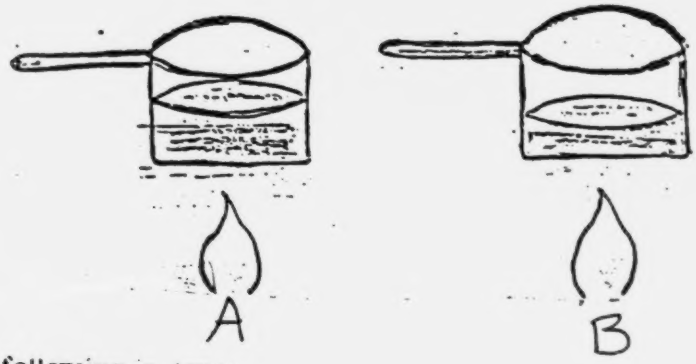
c. There is no difference between heat and temperature except that temperature measures heat.

d. The size of something affects how much heat it contains but doesn't affect the temperature.

e. More of the same temperature water can give off more heat.

f. Temperature is how hot something is and heat is the amount of energy it gives off.

11. We have two pots of water on the stove (see diagram). Both pots of water are on identical flames. Pot (A) has more water in it than pot (B). We bring the temperature of both pots of water from 20 degrees to 50 degrees.



Which of the following is true:

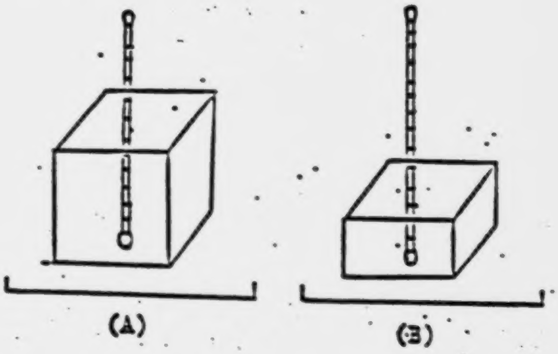
a. Pot (A) takes longer to heat up.

b. Since they are the same temperature, they have received the same heat.

c. Both pots take the same amount of time to get to 50 degrees because they are on the same flame.

d. You need to put more heat in (A) because there's more mass of water for the heat to move through.

12+13. We have two pieces of steel (see diagram). (A) is twice as big as (B). We heat the pieces of stel on identical hot plates for one minute which is not enough time for the steel to reach the temperature of the hot plates. Please answer the following questions.



12. Suppose we have thermometers in each piece of steel and we read them after the minute is up. Which of the following would be true:

a. The smaller piece of steel has a higher temperature because it stored the same amount of heat in a smaller volume.

b. They are the same temperature because the same heat was applied for the same length of time.

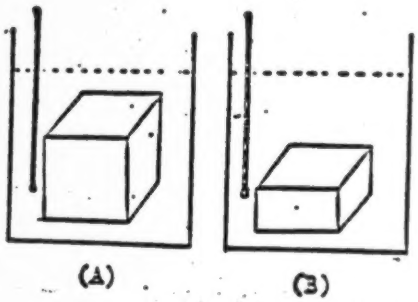
c. The temperatures are the same because they received the same amount of heat.

d. The bigger one is at a lower temperature because it didn't gain as much heat as the smaller one did.

e. The big one has a higher temperature because it absorbed more heat.

f. The big one has a lower temperature because it takes longer to heat up.

13. Suppose that after heating up the two pieces of steel for one minute, we drop them into identical containers of water. The containers of water have thermometers in them (see diagram). After a couple of minutes we read the thermometers in the water.



Which of the following is true:

a. The temperatures are the same because although the smaller piece has a higher temperature, the bigger one has more mass so it equals out.

b. The temperatures are the same because the two pieces of steel are at the same temperature.

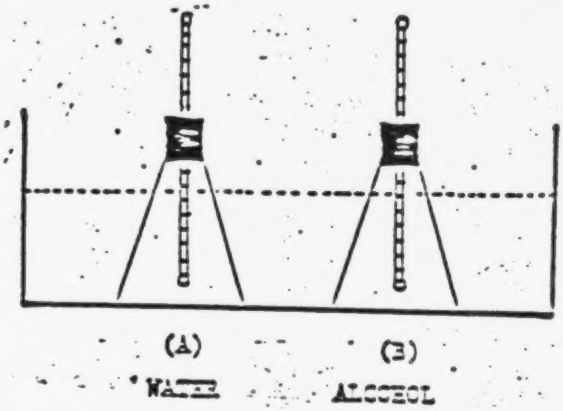
c. The temperatures are the same because the two pieces of steel give the same amount of heat to the water.

d. The water in (B) has a higher temperature because the small piece of steel has a higher temperature.

e. The water in (A) has a higher temperature because the bigger piece of steel has more heat in it, so it gives more heat to the water.

f. The water in (A) has a higher temperature because the bigger piece of steel has more surface area coming into contact with the water.

14. Suppose we have equal amounts of alcohol and water in two identical flasks with thermometers in each (see diagram). We place both flasks in a hot water bath.



Which of the following is true:

a. One of them reaches a higher temperature because it is less dense, so the heat penetrates it more easily. Which is it: (Please circle A or B on your answer sheet)

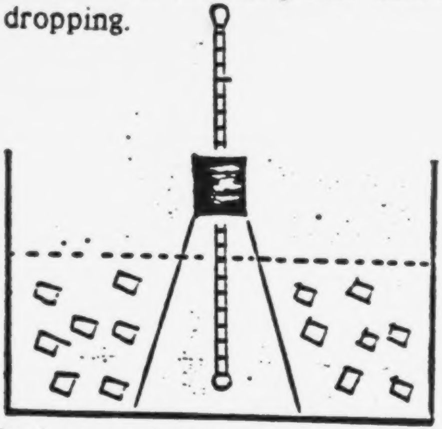
b. One of them reaches a higher temperature because it is more dense, so it absorbs more heat. Which is it: (Please circle A or B on your answer sheet)

c. Both reach the same temperature because they receive the same temperature heat.

d. They reach the same temperature but (A) absorbs a larger amount of heat than (B).

e. They reach the same temperature and they receive the same amount of heat.

15. Suppose we have a flask of alcohol sealed with a rubber stopper. A thermometer is inserted through a hole in the stopper into the alcohol. The thermometer reads 40 degrees. We place the flask in a container filled with a mixture of ice and water (see diagram) and observe that the temperature starts dropping.



Why do you think the temperature goes down?

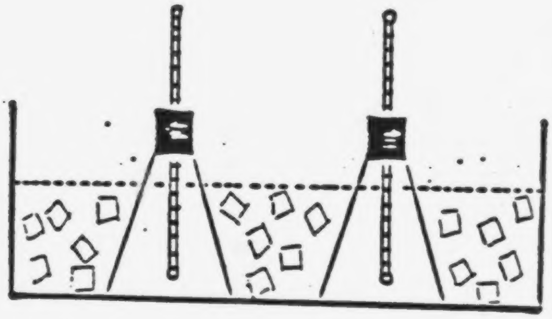
a. The ice lets off coldness which goes into the alcohol.

b. The heat from the alcohol goes into the ice.

c. The alcohol gives hotness to the ice and the ice gives coldness to the alcohol until they reach the same temperature.

d. The ice absorbs the heat from the alcohol.

16+17. Suppose we have two substances at 50 degrees in an ice water bath which is at zero degrees. Substance (A) freezes at 20 degrees. Substance (B) never freezes.
(Note: The ice in the ice water bath never melts).



16. We watch the thermometer in substance (A) for a while. What will we see?

a. The temperature drops to 20 degrees and stops because once something freezes it's temperature can't go lower.

b. The temperature drops to 20 degrees and while the substance freezes it stays at 20 degrees, then it drops to zero.

c. The temperature drops to 20 degrees, the substance freezes, then the temperature starts going down again and doesn't stop.

d. The temperature steadily drops to zero and stops there, but the substances starts freezing when it reaches 20 degrees.

17. Now we watch the temperature of substance (B). What will we see?

a. The temperature drops to zero because that's the temperature of the ice water bath.

b. The temperature keeps dropping because it never reaches the freezing point.

c. The temperature stops a little above zero because if it reached zero it would freeze.

d. It has to freeze at zero.

e. It stops at zero because the ice doesn't give it any more coldness.

f. It keeps going down because the ice keeps applying coldness to it.

g. It stops at zero because the ice can't absorb any more heat from the substance.

18. Suppose you put a thermometer in a big ice cube and one is an small ice cube.

Which of the following is true:

a. The temperature is the same in both ice cubes.

b. The temperature is lower in the big ice cube because it has more coldness.

c. The temperature is lower in the small ice cube because the coldness is more condensed.

d. The temperature is lower in the big ice cube because it cools other things more.

e. The temperature is the same in both ice cubes but the bigger one has more of the same temperature coldness.

f. They are the same temperature and the same coldness.

19. Will a big ice cube cool a drink more than a small ice cube or will they both cool it the same?

a. The big one cools it more because it doesn't melt as fast.

b. The big one cools it more because it absorbs more heat.

c. The big one cools it more because it lets off more coldness.

d. The big one cools it more because more heat transfers to it.

e. The big one cools it more because it comes into contact with more of the drink.

f. They cool it the same because the ice cubes are the same temperature.

g. They cool it the same but the big one might keep it cold for a longer time.

h. They cool it the same because they have the same coldness.

i. They cool it the same but the big one might cool it faster.

APPENDIX 11

Quanititative Problems Test. 1986 Study

Newton North High School
May 1986

PRETEST

Do not write on these sheets. Write your answers on a separate sheet.

1. A quantity of heat is put into 100g of water and causes that water's temperature to rise 20°C. If the same quantity of heat is put into 200g of water what temperature rise will it cause?

a) 40°C   b) 20°C   c) 30°C   d) 10°C

2. You start with the same quantity of water and alcohol both at room temperature. You heat them on identical hot plates for the same amount of time. The temperature of the water reaches 60°C. What temperature will the alcohol reach?

a)60°C   b)more than 60°C   c)less than 60°C

3. Two units of heat are put into 100g of water at 25°C (Beaker 1) and four units of heat are put into 200g of water at 50°C (Beaker 2.) Which of the following is true?

a)The temperature change in beaker 1 is less than the temperature change in beaker 2

b) The temperature change in beaker 1 is more than the temperature change in beaker 2

c)The temperature change in beaker 1 is the same as the temperature change in beaker 2.

d)The final temperature is the same in beaker 1 and in beaker 2

e)None of the above

4. The measure of temperature is
   - a) read on a thermometer
   - b) the same as the measure of heat
   - c) the specific heat of a substance
   - d) the total energy of the molecules of a substance
   - e) both A) and B)

5. You put the same amount of heat into equal masses of rubber and gold. The temperature of the rubber increases by 10^{0}C. The temperature of the gold increases by 100^{0}C. Which of the following is true?
   - a) Gold has a higher specific heat than rubber
   - b) Rubber has a higher specific heat than gold.
   - c) Gold and rubber have the same specific heat.
   - d) One cannot tell from the information given whether gold or rubber has a higher specific heat

6. After heating the pieces of rubber and gold as described in question 5 you drop them in identical containers of cold water. The piece of rubber is in beaker 1 and the piece of gold is in beaker 2. Which of the following is true?
   - a)The final temperature in beaker 1 will be higher than the final temperature in beaker 2
   - b)The final temperature in beaker 2 will be higher than the final temperature in beaker 1
   - c)The final temperature in beaker 1 and in beaker 2 will be equal.

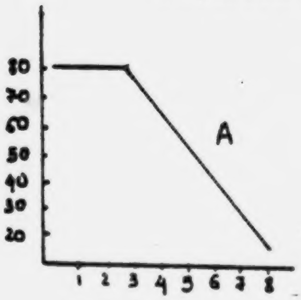
7. The specific heat of steel is higher than the specific heat of silver. 200g of steel and 200g of silver are both heated to 60^{0}C. They are placed in identical containers of cold water. Which of the following is true:
   - a)the silver makes the water hotter than the steel does
   - b)the steel makes the water hotter than the silver does
   - c)the water reaches the same temperature in the two containers.

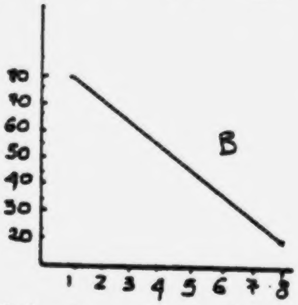
8) When heat is added to a substance, the molecules
- a)increase in size
- b) increase in energy
- c)increase in mass
- d) start dividing

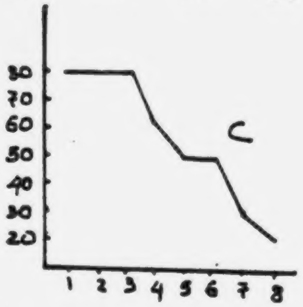
9) Which graph below best represents the data in the following table:

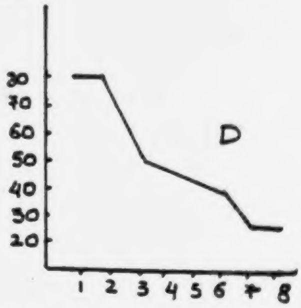
a) b) c) d)

Time(minutes)	1	2	3	4	5	6	7	8
Temperature ^{0}C)	80	80	80	60	50	50	30	20



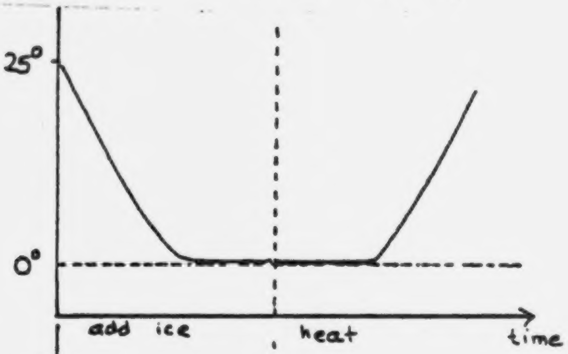


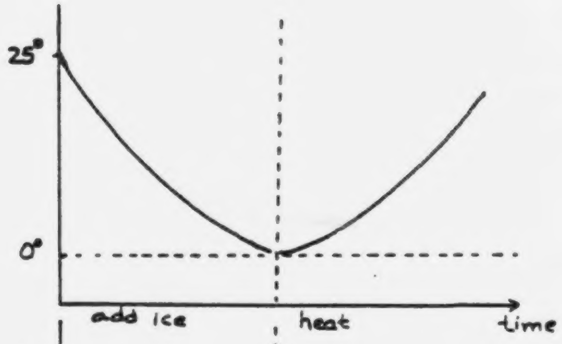


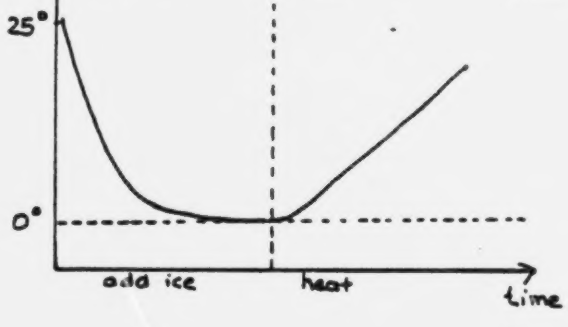


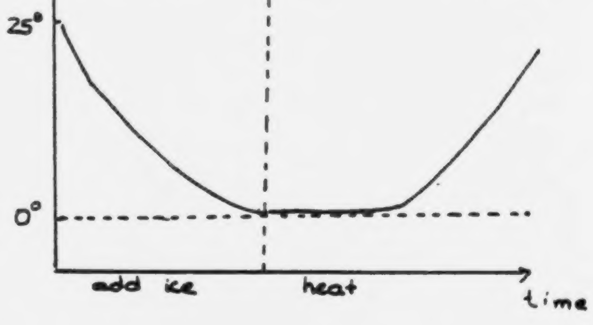
10)You have a beaker of room temperature water (25^{0}C). You add ice to it, let it melt, and keep adding ice until it stops melting. Then you put the beaker of ice/water mixture on a hot plate and heat it until the ice is all melted and the water warms up. Which of the following graphs represents the temperature in the beaker

a) b) c) d)









11.A lump of hot iron raises 100g of water from 30°C to 60°C. An identical lump of hot iron will raise 100g of water from 50°C to

a)80°C b)100°C c)60°C d) none of the above

12.The thermometer is in a beaker of ice and water. It reads 0°C. We put the beaker on a hot plate for a minute. After that time there is still some ice left in the beaker. What does the thermometer read?

a) Less than 0°C b) 0°C c) More than 0°C

13) How many calories must be added to 50g of water to raise its temperature by 10 C?

a)500 b)10 c)50 d)5

14)It takes 600 calories to melt 200g of a substance. What is the latent heat of fusion of that substance?

a) .33 b)120,000 c) 3 d)600

What is the unit for latent heat of fusion?

15) 1 unit of heat raises the temperature of a quantity of copper from 10°C to 15°C. 2 units of heat will raise the temperature of the same quantity of copper from 5 C to:

a)10°C b) 30°C c) 20°C d) 15°C.

16) A block of lead A is placed on a hot plate and kept on it for 2 seconds. Another block of lead B, twice as big and at the same initial temperature as block A, is placed on an identical hot plate and kept on it for 4 seconds. Neither has time to reach the temperature of the hot plate. The final temperature of block B is:

a) the same as the final temperature of block A
b) higher than the final temperature of block A
c) lower than the final temperature of block A

17) If 200 calories are necessary to raise the temperature of 1g of substance by 5^{0}C, how many calories will it take to raise the temperature of 10g of the same substance by 2^{0}C?

a)2,000 b)80 c) 1,000 d)800

18) One cup of oil is poured in pot A and 2 cups of the same temperature oil are poured in pot B. The two pots are kept on identical hot plates for the same amount of time. The temperature in pot A reaches 70^{0}C. What is the temperature reached in pot B

a) 35^{0}C b)70^{0}C c)140^{0}C d)100^{0}C

19) Two steel balls have a 60^{0}C temperature. One weighs 300g and the other weighs 600g. They are both placed in identical containers of cold water. Which of the following is true:

a) the water in the two containers will reach the same temperature

b) the water in container A will reach a higher temperature than the water in container B

c)the water in container B will reach a higher temperature than the water in container A

20) You take a test tube containing hot liquid wax and place it into a beaker of cold water (10^{0}C). After a while, the wax freezes. You are recording the temperature of the wax. Which graph best represents the temperature of the wax

a) b) c) d)

APPENDIX 12

Lesson 1: Heat and Temperature
Computer Group. 1986 Study.

HEAT & TEMPERATURE

PURPOSE: By how much does the temperature of water change when it receives a certain amount of heat?

What is the temperature rise when we double the amount of heat?

What is the temperature rise when we double the amount of water?

Do the temperatures of the same amount of water and alcohol rise by the same number of degrees when they receive the same amount of heat?

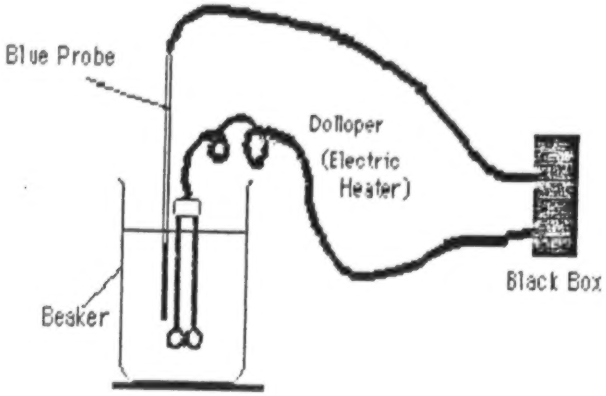
INTRODUCTION:

You are going to use the ***Dollop*** Program. The temperature is recorded with the probe and graphed on the screen as a function of time.

Units of heat energy will be delivered by turning on an electric heater. Every time you press the red button on the black box, a fixed amount of heat is added to the liquid. We will refer to adding heat units as adding **dollops** and the heater will be known as a **dolloper**.

MATERIALS: 150 ml beaker, 250 ml beaker, water, alcohol, electric immersion heater (dolloper), thermal probe.

DIAGRAM



EXPERIMENT 1 Heating 100g of water

To prepare for the experiment:

Pour 100g of water in the 150ml beaker. Place the blue probe and the dolloper into the liquid.

Select the *Dollop* Program.

Type in the data. A good choice is : Time: 250 (sec)
High temperature : 60(oC)
Low temperature: 10(oC)

Press RETURN after each input. A graph will appear on the screen.

To run the experiment

Press S to start.

Measure the initial temperature by pressing T

Deliver 1 dollop of heat. Stir. Watch the temperature rise on the screen. As soon as it levels off, measure the temperature.

The dolloper must always be in the liquid before you deliver a dollop.

Deliver 2 dollops of heat: wait until the light on the box goes off before you deliver the second dollop. Stir. Let the temperature level off, measure the temperature.

Deliver 3 dollops in the same way and then 4 and 5 dollops.

Be sure to perform each step rapidly so that the temperature does not fall before the next units of heat are added.

When the graph is finished, look at the **results**. Press any key; a Table will appear on the screen. Copy it on your Data Sheet.

EXPERIMENT 2 Heating 200g of water

Repeat the sequence above for a sample of 200 grams of water. Use the 250ml beaker. Enter your **results** on your Data Sheet.

EXPERIMENT 3 Heating 100g of alcohol

Repeat the sequence above for a sample of 100g (127ml) of alcohol. Use the 150ml beaker. Enter the **results** on your Data Sheet.

After the experiments are completed and all data are recorded clean up the equipment and return materials as directed by your teacher.

Answer questions on homework sheet and write up your own conclusions for the experiment considering all the data.

NAME:____________________

BLOCK:_____
Date:___/____/___

HEAT & TEMPERATURE
Homework

1. Use your data to predict the temperature rise for the following:
    - a. 6 dollops of heat into 200g of water ____________________.
    - b. 6 dollops of heat into 400g of water ____________________.
    - c. 6 dollops of heat into 200g of alcohol ____________________.

2. Compare the temperature changes caused by 2 dollops and by 4 dollops on 100g of water. About how many times greater was the temperature change for 4 dollops as compared to 2 dollops?

3. Why did the difference in question #2 occur?

4 For 100g of water, compare the temperature rise per dollop when 1 dollop is given, when 2 dollops are given and when 3 dollops are given. Explain.

5. Compare the temperature change caused by 3 dollops on 100g and 200g of water. About how many times greater was the change for 100g as that for 200g of water?

6. Why did the difference in question #4 occur?

7. Compare the temperature change for 2 dollops in 100g of water and in 100g of alcohol. About how many times greater was the change for the alcohol as that for the water?

8. Did you put the same amount of heat energy (heating time) into both the water and the alcohol in question #6?

Guess why this difference in temperature change exists.

9. Predict the temperature change if you added one dollop to 50g of water.

10. Predict the temperature change if you added one dollop to 50g of alcohol.

11. Suppose you wanted to increase the the temperature of 100g of water and 100g of alcohol, If you deliver 2 dollops to the alcohol, about how many might you need for the water?

APPENDIX 13

Lesson 1: Heat and Temperature Control Group. 1986 Study.

HEAT & TEMPERATURE

PURPOSE: By how much does the temperature of water change when it receives a certain amount of heat?

What is the temperature rise when we double the amount of heat?

What is the temperature rise when we double the amount of water?

Do the temperatures of the same amount of water and alcohol rise by the same number of degrees when they receive the same amount of heat?

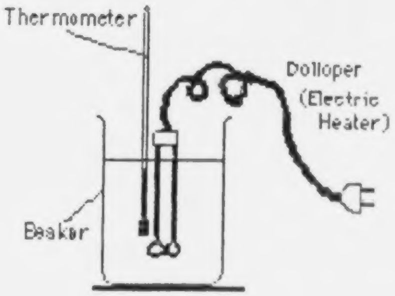
INTRODUCTION:

Units of heat energy will be delivered by turning on an electric heater for a fixed unit of time. A unit of 10 seconds duration will be called a **dollop of heat**. We will thus refer to adding heat units as adding **dollops** and the heater will be known as a **dolloper**.

MATERIALS: 400ml beaker, 600 ml beaker, thermometer, water, alcohol, electric immersion heater (dolloper).

DIAGRAM:

One Heat unit equals 10 seconds of electric energy.



Timing must be done accurately
The dolloper must always be in the liquid before you turn it on.
Stir liquid continually
After completing one trial start next step before temperature drops.

PROCEDURE: 1. Pour 200g of room temperature water in a 400ml beaker.

2. Insert the thermometer and the dolloper (heater) into the water in the beaker.

3. Add one unit of heat by turning the dolloper on for 10 seconds **exactly. (accurate timing is essential for meaningful results.)** Stir. Shut off the dolloper and record the temperature in the data table.

4. Add two more dollops of heat. Stir. Shut off the dolloper and record the new temperature in the data table.

5. Repeat the above sequence for three dollops and finally four dollops of heat recording the temperature each time.

6 *Be sure to perform each step rapidly so that the temperature does not fall before the next units of heat are added.*

7. Repeat this sequence for a sample of 400 grams or water in the 600ml beaker. Enter your results in the data table.

8. Repeat this sequence again with 200 grams of alcohol (254ml) in the 400 ml beaker. Enter your results in the data table.

9. After the experiment is completed and all data is recorded clean up the equipment and return materials as directed by your teacher.

10. Calculate the rise in temperature for each trial and record in data table.

11. Graph the results (temperature change vs number of dollops) for each of the three liquids on the same graph. Use a different color or symbol for each plot. Draw the best straight line for each liquid. Label each line with the amount and kind of liquid.

12. Answer questions on homework sheet and write up your own conclusions for the experiment considering all the data.

Name: **Block:**
Date

HEAT & TEMPERATURE
Homework

1. Use the data to predict the temperature rise for the following:
   a. 6 dollops of heat into 200g of water ____________________________________
   b. 6 dollops of heat into 400g of water ____________________________________
   c. 6 dollops of heat into 200g of alcohol ____________________________________

2. Compare the temperature change of 20 seconds heating time and 40 seconds heating time on 200g of water. About how many times greater was the temperature change at 40 seconds as that for 20 seconds?

3. Why did the difference in question #2 occur?

4. For 200g of water, compare the temperature rise per dollop when 1 dollop is given, when 2 dollops are given and when 3 dollops are given. Explain.

5. Compare the temperature change of 30 seconds heating time on 200g and 400g of water. About how many times greater was the change for 200g as that for 400g of water?

6. Why did the difference in question #4 occur?

7. Compare the temperature change of 40 seconds heating time of 200g of water and 200g of alcohol. About how many times greater was the change for the alcohol as that for the water?

8. Did you put the same amount of heat energy (heating time) into both the water and the alcohol in question #6?

   Guess why the temperature differences are not the same.

9. Predict the temperature change if you added one dollop to 50g of water.

10. Predict the temperature change if you added one dollop to 50g of alcohol.

11. Suppose you wanted to increase the temperature of 100g of water and 100g of alcohol by the same number of degrees. If you deliver 2 dollops to the alcohol, about how many might you need for the water?

APPENDIX 14

Lesson 2: Heat Storage Capacity Computer Group. 1986 Study.

SPECIFIC HEAT/ HEAT STORAGE IN SUBSTANCES

PURPOSE. To measure and compare the amount of heat energy stored in different substances by heat flow transfer.

INTRODUCTION:

When heat is absorbed by a substance and if the substance does not change state (melt, freeze, evaporate), the substance will increase in temperature. You know that the temperature increase depends on the amount of heat absorbed by the substance: a larger amount of heat causes a larger temperature increase. The temperature increase also depends on the mass of substance being heated: if the same amount of heat is absorbed by a larger mass, the temperature increase will be less.

The first question you will be investigating here is whether the temperature of all substances increases by the same number of degrees when they receive the same amount of heat. Remember the water and the alcohol! You are going to heat lead and aluminum with the dolloper and measure their temperature with the probe. Then you will use a new computer program-a *computer simulation*- to experiment with other substances like oil and mercury. With the computer simulation, you program the experiment and everything takes place on the screen. The computer program imitates the activities you performed yourself but it simplifies your work and eliminates difficulties like handling dangerous or messy substances like mercury and oil.

The second question is whether all substances, when they cool, release the same amount of heat. You will find out by using the computer simulation. You will start with different hot substances at the same temperature, mix them with cold water, and measure the temperature rise in the water. If two substances release the same amount of heat when they cool, they should should have the same effect on the temperature of the water. But if the final temperature in the water is not the same, then the two substances have transferred different amounts of heat to the water, although they were at the same initial temperature.

MATERIALS. A small insulated beaker, a large insulated beaker, dolloper, thermal probe, water, aluminum beads and leads shots.

EXPERIMENT 1

1)Put the dolloper and the probe in the large beaker. Tape the probe carefully to the inside of the beaker. Pour 200g of aluminum beads in a beaker. Cover.

2) Start the *Dollop* program. Record the temperature. Deliver 2 dollops of heat to the aluminum. Shake the container well to distribute

the heat throughout the aluminum beads. When the temperature stabilizes, record it.

3)Write down the temperature of the aluminum before and after you delivered the dollops. Calculate the temperature rise. Enter in your Data Table.

4)Repeat with 200g of lead in the small beaker. Enter the results in your Data Table.

EXPERIMENT 2

Now you are going to perform the same kind of experiments but with the Computer Simulation.

1)Load the Simulation Program

2)The menu shows 4 samples. Start with water. You may experiment with the samples in any order you want and repeat any sample if you wish.

3)For each sample:

- Deliver one dollop of heat by pressing "H".
- Record the temperature rise for one dollop.
- Add 4 more dollops. Record the temperature rise.
- Transfer the sample into 100g of water at 20°C by pressing "C"
- When the temperature in the water levels off, record the temperature rise.
- Enter the results in your Data Table.

4)Repeat with the other 3 samples.

EXPERIMENT 3

This experiment is very similar to Experiment 2 except that you will deliver enough dollops to each sample to make their temperature rise by the same number of degrees.

1)Start with mercury. Deliver 1 dollop. Record the temperature rise.

2)Select another sample. Deliver dollops until the temperature rise is the same as for the mercury (within a few tenths of a degree). Record the number of dollops you delivered. Enter in your Data Table.

3) Repeat with the other 2 samples.

Name: **Block:**

SPECIFIC HEAT : DATA TABLE

Experiment 1

Substance	Temperature rise for 2 dollops
Aluminum	
Lead	

Experiment 2

Substance	Temp. rise for 1 dollop	Temp. rise for 4 dollops	Temp. rise in water
Water			
Oil			
Sand			
Mercury			

Experiment 3

Substance	Number of dollops	Temp. rise	Temp. rise in water
Mercury	1		
Water			
Sand			
Oil			

Name **Block**

Homework

1) Look at the data from Experiment 2.

Did you put the same amount of heat in each sample?

Was the temperature rise the same in each sample?

Can you explain why the temperature rise differed from sample to sample?

Was the temperature rise in the water approximately the same for each sample?

Why?

2)Suppose that in Experiment 1 you had mixed the aluminum beads and the lead shots each with 100g of cold water after giving them 2 dollops each. Which one would have made the water warmer, or would they have raised the water temperature by the same number of degrees?

Why?

3) Look at Experiment 3. Were the four samples at approximately the same temperature before you mixed them with the water?

Did they cause the same temperature rise in the water?

Can you explain this result?

4) Look at Experiment 1. How many dollops would you need to make the aluminum as hot as the lead?

Suppose both the aluminum and the lead are at the same temperature (for example 100^{0}C). You mix them each with 100g of cold water. Which one would make the water warmer, or would they raise the water temperature by the same number of degrees?

Why?

5) Look at Experiment 2 . Order the four samples according to their temperature rise for 2 dollops, from the largest to the smallest rise.

________ ________ ________ ________

6) Look at Experiment 3. Order the four samples according to the number of dollops they needed to reach the same temperature from the smallest number to the largest number of dollops.

________ ________ ________ ________

7) Look at Experiment 3. Order the four samples according to their effect on the temperature of the water from the smallest rise to the largest rise.

________ ________ ________ ________

8)Compare the orders you found in Question 5, Question 6 and in Question 7 Explain.

9) Suppose you had been using 200g of cold water instead of 100g in Experiment 3. What would the water temperature rises have been for each sample?

Water: Sand: Oil: Mercury:

10) The property of substances you have been investigating is called **Specific Heat** or **Heat Storage capacity.** To say that substance A has a higher specific heat than substance B means:

A.It takes more heat to raise the temperature of 1g of substance A by 1°C than to raise 1g of substance B by 1°C.

B. If the same amount of heat is given to 1g of substance A and to 1g of substance B, the temperature of substance B will rise more.

C.When 1g of substance A and 1g of substance B cool by 1°C, substance A releases more heat than substance B.

Which has a higher specific heat: aluminum or lead?

Order the 4 samples in order of increasing specific heat.

________ ________ ________ ________

APPENDIX 15

Lesson 2: Heat Storage Capacity Computer Group. 1986 Study.

ENERGY STORAGE CAPACITY OF SUBSTANCES/SPECIFIC HEAT

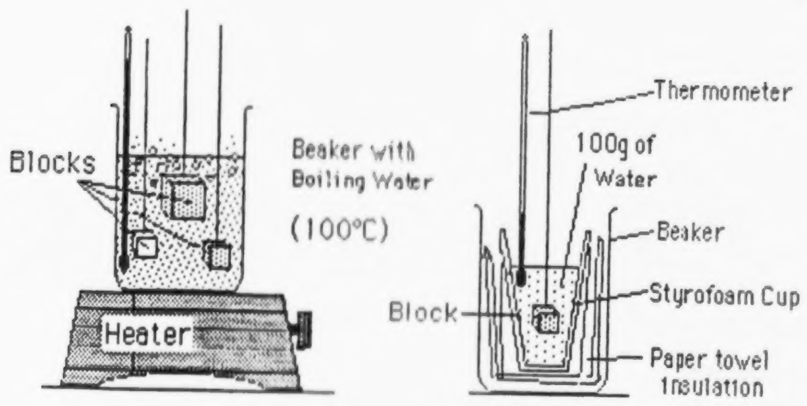
PURPOSE: What difference is there in the heat storing capacity of different materials when measured by heat-flow transfer?

INTRODUCTION: When heat is absorbed by a substance and if the substance does not change state (melt, freeze, evaporate), the substance will increase in temperature. You know that the temperature increase depends on the amount of heat absorbed by the substance: a larger amount of heat causes a larger temperature increase. The temperature increase also depends on the mass of substance being heated: if the same amount of heat is absorbed by a larger mass, the temperature increase will be less. You also know that if you put the same amount of heat into teh same mass of water and alcohol, the temperature rise will be different. The temperature rise for a given amount of heat and a given mass of substance depends on the substance.

The question you will be investigating today is whether all substances release the same amount of heat when their temperature decreases by the same number of degrees. You are going to start with blocks of iron and aluminum at the same high temperature (100°C.) You will drop them in cold water and measure the temperature rise in the water. If two substances release the same amount of heat when they cool, they should should have the same effect on the temperature of the water. But if the final temperature in the water is not the same, then the two substances have transferred different amounts of heat to the water, although they were at the same initial temperature.

Before performing this activity predict which will heat the water more: iron or aluminum.

MATERIALS: 250ml beaker, 600ml beaker, styrofoam cup,100ml graduated cylinder, electric heater, balance, thermometer. There are three blocks: a large aluminum block (50g), a small aluminum block (17g), and an iron block (50g). Notice that the iron block has the same mass as the larger aluminum block but the same size as the smaller aluminum block. All three are heated to 100ºC in a beaker of boiling water.


Blocks
Beaker with Boiling Water
(100°C)
Heater
Thermometer
100g of Water
Beaker
Block
Styrofoam Cup
Paper towel insulation

PROCEDURE:

1. Mass each block and record on the data table.

2. Place the blocks in a 600ml beaker of boiling water with the attached thread hanging to the outside of the beaker.

3. Wrap a styrofoam cup with an insulating paper towel and fit into a beaker.

4. Add 100 grams of water to the cup. Take the temperature and record it in the data table.

5. Using the thread move the larger aluminum block from the boiling water to the cup.

6. Stir the water continually.

7. Measure and record in the data table the highest temperature the water reaches after it stops rising.

8. Repeat the experiment using the other two blocks and a new 100 gram sample of water for each.

9. Clean up your equipment.

Data Table:

block	Mass of Block	Starting Water Temperature	Final Water Temperature	Change in Temperature
Large Aluminum Block	g	° C	° C	° C
Small Aluminum Block	g	° C	° C	° C
Iron Block	g	° C	° C	° C

NAME:________________ BLOCK:_____

HOMEWORK

1. Write the actual temperature change of water caused by the large aluminum block: ________________________________.

2. Using the data table and the answer to question #1, compute the temperature rise per gram for the large aluminum block.

> **Temperature rise per gram** means: How much does each gram of aluminum contribute to the temperature rise in the water.
>
> **Here is an example:** If 100g of aluminum at 100ºC raises the temperature of cold water by 20ºC each gram of aluminum contributed (20ºC/100g) 0.2 ºc/gram to the temperature rise.

3. Write the actual temperature change of water caused by the small aluminum block: ________________________________.

4. Using the data table and the answer to question #3, compute the temperature rise per gram for the small aluminum block. ______________

5. Write the actual temperature change of water caused by the iron block:

________________________________.

6. Using the data table and the answer to question #5, compute the temperature rise per gram for the iron block _________________________

7. Were all the blocks originally at the same starting temperature? Explain how you know.

8. List the blocks in the order in which they affected the temperature of the 100g sample of water:

1.______________________
2.______________________
3. ______________________

9. All the blocks were initially at the same temperature. Why didn't they cause the same temperature changes in the water?

10. The iron block has the same volume (size) as the small aluminum block. Why didn't it make the water rise by the same number of degrees?

11. The iron block has the same weight (mass) as the large aluminum block. Why didn't it make the water temperature rise by the same number of degrees?

12. Compare the temperature rise per gram results computed in questions #2, #4, and #6. Are the blocks the same in any way? HOW?

How do the blocks differ?

What characteristic determines a difference in the temperature rise per gram? (size? mass? material?)

13) The property of substances you have been investigating is called **Specific Heat.** To say that substance A has a higher specific heat than substance B means:

1. It takes more heat to raise the temperature of 1g of substance A by 1°C than to raise 1g of substance B by 1°C.

2. If the same amount of heat is given to 1g of substance A and to 1g of substance B, the temperature of substance B will rise more.

3. When 1g of substance A and 1g of substance B cool by 1°C, substance A releases more heat than substance B.

Which has a higher specific heat: aluminum or lead?

14. Suppose you have 200 g of cold water in the styrofoam cup instead of 100 g. Use your data table to predict the temperature rises that might be caused as you lower each block into the water. (Each block is at 100ºC)

Large Alu : ______ºC Small Alu : ______ºC Iron:________ºC

15. Suppose the three blocks are sitting in a a mixture of water and ice (at a temperature of 0ºC). Which block would need the most heat to raise its temperature to 20ºC (room temperature)?

Which block would need the least?

Suppose it takes 9 dollops of heat to raise the temperature of the large aluminum block to 20ºC from 0ºC, how many dollops might be required to heat the small aluminum block to the same temperature?

How many dollops for the iron block?

APPENDIX 16

Lesson 3: Latent Heat
Computer Group. 1986 Study.

LATENT HEAT

ENERGY TO MELT ICE

PURPOSE: What is the relationship between heat and temperature when ice melts and water is heated?

MATERIALS: 250ml Beaker containing 75ml of room temperature water, two cups 2/3rd full of crushed ice, electric emersion heater (dolloper), , blue probe.

PROCEDURE: 1. Pour 75g of room temperature water in a 250ml beaker. Place the blue probe in the beaker so that it does not touch the beaker but is fully submerged in the water.

2.Select the **Dollop** program. When prompted set the time to 800 seconds, high temperature to 30 C and low temperature to -10 C.

3. You are now going to record the temperature as you first add ice and then add dollops of heat.

4. Press **S** to start. Wait 50 seconds. Press **T** to record the temperature. Add 2/3 cup of crushed ice to water in the 250ml beaker. Stir and record temperature of the ice/water mixture when it levels off.

5. Add another 2/3 cup of crushed ice to water in the 250ml beaker. Stir and record the temperature of the ice/water mixture from time to time .

6. At 200 seconds, place heater into ice/water mixture. Deliver 1 dollop about every **15 seconds**, stirring vigorously with the heater after each dollop. Record temperature every 100 seconds as marked on the graph. .

7 Write down at what time the ice aahs completely disappeared. COntinue to deliver dollops.

7. **Do NOT press any key to continue.** If you do the graph would disappear!

8. Copy the graph. Do not forget to label the axes and to write down the temperature readings.

9. Note on the graph when the ice was all melted.

10. Clean up your equipment and answer questions on homework sheet.

NAME:____________________ BLOCK:_____

GRAPH

Homework

1. Describe the transfer of heat at the beginning of the experiment (when you added the first batch of ice). To and from what was heat being transfered?

2. Explain why the temperature did **not** drop when you added the second batch of ice?

3. What did the temperature do when you started to add heat. (Look at your graph!)

4. Why did the temperature act as it did when you added heat to the water/ice mixture.?

5. What happened to the temperature after all the ice has melted?

6. In what state was the mixture when the temperature started to rise?

7. Suppose we put warm water in a freezer (-10ºC) and record its temperature. Draw a temperature graph on the back of this page as a function of time. (Try it.)

APPENDIX 17

Lesson 3: Latent Heat
Computer Group. 1986 Study.

LATENT HEAT

ENERGY TO MELT ICE

PURPOSE: What is the relationship between heat and temperature when ice melts and water is heated?

MATERIALS: 250ml Beaker containing 75ml of room temperature water, two cups 2/3rd full of crushed ice, electric emersion heater (dolloper), thermometer, 1 hole stopper, clamp, clock, stirring rod.

PROCEDURE: 1. Pour 75ml of room temperature water in a 250ml beaker. Place a thermometer in the beaker using a clamp and stopper to support it so that it does not touch the beaker but is fully submerged in the water.

2. Record the temperature of the water. Write it in your Data Table.

3. Wait 60 seconds and record the temperature again. Write it in your Data Table.

4. Add 2/3 cup of crushed ice to water in the 250ml beaker. Stir vigorously and record the temperature of the water when it levels off. Write it in your Data Table.

5. Add another 2/3 cup of crushed ice to water in the 250ml beaker. Stir vigously and record the temperature of the ice/water mixture. Continue stirring and recording every 20 seconds, four times. Write it in your Data Table.

6. Quickly place heater into ice/water mixture. Plug heater into electric outlet for a **5 second** heat unit. Then remove plug. Record temperature while stirring ice/water mixture. Write it in your Data Table.

7. **15 seconds later** after removing plug from outlet, plug it in again for **5 second heat unit** and remove plug. Record temperature of the ice/water mixture while stirring. Write it in your Data Table.

8. Continue adding **5 second heat units**, separated by intervals of **15 seconds.** Record temperature after every other 5 second heat unit. Write it in your Data Table. Continue stirring. **Watch the ice**. How rapidly does it melt?

9. Continue until **24** "5 second heat units" have been added to the mixture recording the temperature after each 5 second heat unit. Write it in your Data Table. **Note on the Data Table when the ice was all melted.**

10. Clean up your equipment.

11. Plot Graph and answer questions on homework sheet.

NAME:____________________
BLOCK:_____

LATENT HEAT DATA TABLE

TIME	TEMPERATURE	STATE OF THE MIXTURE
________	________	Water
________	________	Water
		Add 2/3 cup ice
________	________	________
		Add another 2/3 cup ice
________	________	Water+ice
________	________	Water+ice
________	________	Water+ice
________	________	Water+ice
		Start heating
________	________	________
________	________	________
________	________	________
________	________	________
________	________	________
________	________	________
________	________	________
________	________	________
________	________	________
________	________	________
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GRAPH

Homework

1. Describe the transfer of heat at the beginning of the experiment (when you added the first batch of ice). To and from what was heat being transfered?

2. Explain why the temperature did **not** drop when you added the second batch of ice?

3. What did the temperature do when you started to add heat. (Look at your graph!)

4. Why did the temperature act as it did when you first added heat to the water/ice mixture?

5. What happened to the temperature after all the ice was melted?

6. In what state was the mixture when the temperature first began to rise?

7. Suppose we put warm water in a freezer (-10ºC) and record its temperature. Draw a temperature graph on the back of this page as a function of time. (Try it)